LABORATORY MANUAL
OF
TESTING MATERIALS

LABORATORY MANUAL
OF
TESTING MATERIALS

BY

WILLIAM KENDRICK HATT, C.E., Ph.D.

MEMBER AMERICAN SOCIETY CIVIL ENGINEERS; PROFESSOR OF CIVIL ENGINEERING, AND DIRECTOR OF LABORATORY FOR TESTING MATERIALS, PURDUE UNIVERSITY

AND

H. H. SCOFIELD, M.E.

ASSISTANT PROFESSOR IN LABORATORY FOR TESTING MATERIALS, PURDUE UNIVERSITY

McGRAW-HILL BOOK COMPANY, Inc.
239 WEST 39TH STREET, NEW YORK
6 BOUVERIE STREET, LONDON, E. C.
1913

THE · MAPLE · PRESS · YORK · PA

PREFACE

This manual is the outcome of the operation, through eighteen years, of the Laboratory for Testing Materials of Purdue University. During this time several instructors, temporarily serving the laboratory, have improved its practice. Especial mention should be made of the services of the late Professor Hancock, whose untimely death deprived the science of testing materials of a very able and patient investigator, and his colleagues of a good friend. Professor Yeoman, now of Valparaiso University, did valuable service in the organization of the work of the cement laboratory. The authors are indebted to Professor Poorman of Purdue University, for valuable suggestions.

In its original form the manual was published by the senior author of this volume; and later, with the assistance of Professor Scofield, the manual was enlarged, and was found useful in several universities. Now the authors have availed themselves of the assistance of the present publishers to enlarge the work. The list of experiments has been increased, and a more complete treatment of machines and apparatus added.

One purpose of the manual is to relieve the instructor from the necessity of explaining the details of mechanical procedure, and so to free his time for matters of greater educational importance. It is also hoped by the authors that the practitioner will find the volume of convenient use.

LAFAYETTE, IND.,
August, 1913.

CONTENTS

LABORATORY MANUAL OF TESTING MATERIALS

CHAPTER I

General

1. The student should obtain a knowledge of materials by handling them and watching their behavior under stress. From the appearance before and after test, he is led to recognize the nature of normal and defective samples. This knowledge will give character to the work of engineering design, and will be of service in work of inspection.

2. A knowledge of the technique of testing materials should be gained, by which he may know afterwards if proper methods are being used in cases that come under his inspection, and by which he may judge the significance of results of the tests of material submitted to him.

3. A training should result in precise methods of observation.

4. The class-room instruction in Applied Mechanics which precedes or accompanies this course, is reinforced with concrete knowledge of things and properties, which are otherwise only words defined in text-books. The application of theoretical analysis to the tests performed in the laboratory becomes of individual interest and is fixed in the mind. Discrepancies between theoretical deductions and results of tests of actual material as

supplied to the market also become evident. Many of the fundamental facts relating to metals, such as the relative stiffness of hard and soft steel, the elevation of the yield point, and the lowering of the elastic limit through overstrain can also be brought to the student's notice by a few well-selected experiments.

5. Work is assigned from day to day according to the progress of the student. The laboratory work is self-contained, *i.e.*, the work is all to be performed during the time assigned by the faculty. From time to time lectures are given explaining the manufacture and properties of the common materials tested, and the technique of testing.

6. The student should refer to standard text-books and specifications to compare the results obtained with recorded data.

The specifications on hand are: American Society for Testing Materials; Pennsylvania Railroad; J. I. Case Threshing Machine Company; American Locomotive Company; Specifications for Inspection of Steel and Iron Material for Hulls and Hull Fittings of Vessels of U. S. Navy; U. S. Army Specifications for Material, etc. The volumes in the laboratory are, in part: "Reports of Tests of Metals, Watertown Arsenal"; "Materials of Construction," by J. B. Johnson; "Masonry Construction," by I. O. Baker; "Handbook of Testing Materials," by A. Martens (translated by Gus Henning); Unwin's "Testing the Materials of Construction"; "Concrete, Plain and Reinforced," Taylor & Thompson; "Bulletins of the Forest Service.

7. Thesis work in testing materials presents a ready and attractive medium by which students can receive some training in proper methods of planning and executing experimental investigations. The work may be individual, or performed by groups of students, and

the expense of material is small. If the professor is interested in some one field of investigation and systematically plans for a term of years, the theses in time are of use in extending knowledge."

The method of administering thesis work in general involves the following steps: A list of problems, to which, on account of limitations of equipment and the desire to concentrate, the work of the laboratory should be confined, is prepared early in the year. Theses subjects are generally chosen from this list by students. When a subject is chosen by a student, a thesis outline is prepared by the professor in consultation with the student, in which the problem is clearly stated; the authorities, if any, cited; a list of literature, or directions to main source of information given; and the main plan of attack fairly definitely indicated. Details of apparatus, etc., are generally left to the student. A student may present a subject of his own choice. The written thesis covers a clear and logical account of the purpose of the thesis; the material tested; the methods and machines, with a discussion or error; the actual results; the analysis and presentation of the results; and the conclusions therefrom. All data remain the property of the university and publication of the results may only be made by the student with the consent of the University authorities.

CHAPTER II

General Instructions

Preliminary Notes.—In all tests, first carefully examine the material. Measure, and note characteristics and defects, if any. If this is not done before the specimen is broken, the test is useless. Note the serial number if any.

The character of the log sheet will be considered in grading the report.

The student should understand the manipulation and reading of all instruments used in each test.

Enough readings should be taken to accurately determine the stress-strain curve. Calculate from table of average strengths of materials, see appendix, the increment of loading required to give at least 18 readings. When quantities being measured are changing rapidly, intervals must be shortened.

Specimens upon which further observations are to be made should be carefully marked and placed in assigned case.

All laboratory notes and data, together with unfinished reports, must be left in the folio case.

Operation of Machines During Test.—Preliminary to every test, each student should become familiar with the operation and mechanism of the testing machine to be used.

Balance poise at zero with test piece in the machine but not clamped.

All readings upon test piece for a certain load should be taken when the beam is balanced at the load and at no

other time. The finger may be used to lift the beam slightly and so give warning which will prevent the loads being exceeded.

The speed of applying the load should be such that the beam may be kept balanced, otherwise the readings will be of doubtful accuracy.

Often after the elastic limit has been reached a faster speed may be used and much time saved. Any consistent speed is allowable if the load readings are accurate, except in experiments for which the machine speed to be used is stated in the instructions. **Students should be sure that machines are properly thrown out of gear when the test is finished.**

Caution.—Testing machines have upon different occasions been left by the operators with countershaft running and the friction clutches thrown in, so that the machines continued running. The result has usually been that some part of the machine was broken. The operator will take especial care that this does not occur with machines for which he is responsible. He will be charged with all the repairs made necessary by careless handling.

Reports.—Reports will be written on Form B paper and placed in the regular manila cover. On the outside of the cover will appear the number of the experiment, folio number, name of student and his co-workers, title of experiment and the day and date performed, all in lettering.

Clearness and order of statement, legibility of writing, lettering and neatness will receive due attention in marking the report.

In plotting stress-strain curves, select such a scale as can easily be read by inspection, in decimals. State plainly the scale of coordinates. Use the bow pen to circle the points plotted, and draw curves with instru-

ments. Pencil in curve first and submit to instructor, then ink in. Use India ink for curves and lettering on the curve sheets. Avoid broken lines from point to point.

The general form of load-deformation curve should be noted. Figure (1) represents a characteristic curve of ductile materials where the curve is drawn a straight line to the elastic limit averaging the plotted points. Figure (2) represents the curve for brittle materials. Select scales of coordinates so that the slope of the portion below the elastic limit is about 60°. As in Fig. 1 when curve does not start at origin draw a parallel line through origin to the elastic limit.

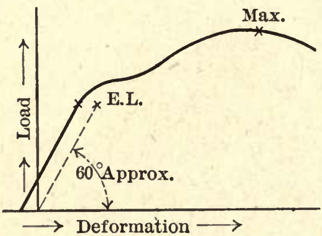


Fig. 1.

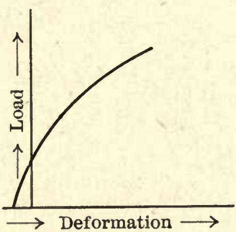


Fig. 2.

Figs. 1 and 2.—Stress diagrams.

The title of the curve sheet should be placed in the lower right-hand corner and should contain such information that a busy man unacquainted with the experiment, glancing at the curve sheet, would grasp the main facts without aid of the written report.

The student will note carefully any characteristics of the curve that are peculiar and state reasons for their appearance and how they can be avoided if they seem to be errors.

Instructions for Writing Reports

The clerical part of the report should be suitable for submission to a practising engineer, who would naturally

judge of the qualifications of the writer by the neatness and system of the report.

The sequence and the form in which the results are presented must be such as to enable a busy man to ascertain in a few moments just what was done and what was determined. *A careful study should be given to economy of language in writing the report.*

The general order of such reports is as follows:

TITLE.—The title should indicate at a glance what the report covers.

PURPOSE.—Under this heading there should be a few lines stating the purpose for which the test is made.

MATERIAL.—Under this heading is given a concise description of the material tested. It is ordinarily sufficient to define the material as to kind, size, shape and condition. A reference should be made to any drawings which may accompany the report in the form of an appendix.

SPECIAL APPARATUS.—Name important apparatus, and describe. This refers only to apparatus special to the test being reported.

METHOD OF TEST.—Under this heading the methods of applying the loads and observing the deformations are given in concise and clear language, and accompanied by a reference to drawings and appendices when necessary.

RESULTS OF TESTS.—The results of the tests are usually given in detail on special form sheets, or they may be given in tables or diagrams in appendices which are referred to in the report by number. It is sometimes necessary to insert in the body of the report a summary of the data.

CONCLUSIONS.—The conclusions to be drawn from the data are presented in numerical order and are supported by reference to the averages of the tables or diagrams

prepared from the tables, and by a *tabular comparison with standard specifications or results quoted by authorities.* Call attention to amount of discrepancy.

Here the student should state any observations tending to verify or refute theoretical laws and the application of the phenomena under consideration to practical engineering problems.

CHAPTER III

Definitions

As supplementing the text-books in mechanics the following definitions are recorded for reference:

For formulas and symbols see Appendix.

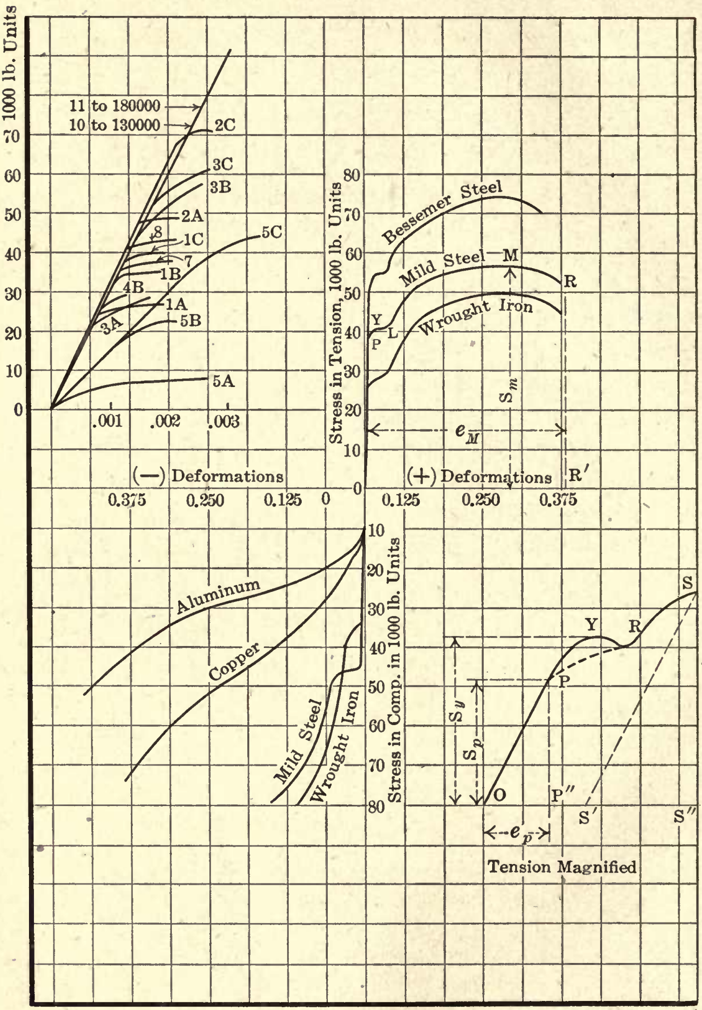
Stress is the internal, equal and opposite, action and reaction between two portions of a deformed body. Stress is a distributed force, and is expressed in force units. As in case of deformations, stresses are: (1) normal, S, either tensile (+) accompanying a lengthening of a bar, or compressive (−) accompanying a shortening of a bar; and (2) tangential or shearing, S_v, when acting parallel to a section and accompanying a change of angle of the faces.

Uniformly distributed normal stress accompanies a load that acts along a geometric axis of a bar.

Unit stress (pounds per square inch) is the amount of stress per unit of area of surface.

The word *strain* is often used to express both deformation and stress. When used below it means deformation.

Stress-strain diagrams (Fig. 3) are drawn from data obtained in tests of materials in which gradually increasing loads are applied from zero until rupture occurs. Unit deformations are shown as abscissae, and unit stresses as ordinates, tension (+) and compression (−). Such diagrams display the most important mechanical properties of materials. Fig. 3 shows several such diagrams. The tension deformations at small loads are shown in magnified scale to the right and the



1000 lb. Units
0
10
20
30
40
50
60
70
11 to 180000
10 to 130000
2C
3C
3B
2A
8
1C
7
1B
4B
1A
3A
5B
5C
5A
.001
.002
.003
(—) Deformations
0.375
0.250
0.125
0
Stress in Tension, 1000 lb. Units
80
Bessemer Steel
Mild Steel
M
R
Wrought Iron
Y
P
L
S m
e M
(+) Deformations
R′
0.125
0.250
0.375
Stress in Comp. in 1000 lb. Units
Aluminum
Copper
Mild Steel
Wrought Iron
S
Y
R
P
S y
S p
O
P″
S′
S″
e p
Tension Magnified

FIG. 3.

relative values of S_p for various materials to the left. The stresses are not actual but nominal, because the load is divided by the original, and not by the actual, deformed area.

ELASTICITY

ELASTICITY is the tendency of deformed bodies to resume their former shape.

ELASTIC LIMIT is the limit of stress within which the deformation completely disappears after the removal of the stress. As measured in tests, and used in design this term refers to the *proportional elastic limit*, S_p, which is the unit stress within which stresses and deformations are directly proportional. At the *Commercial Elastic Limit* or *Yield Point*, S_y, some materials experience a sudden and large increase of deformation without increase of stress. S_p is from 0.75 S_y (hot-rolled steel) to 0.90 S_y (annealed steel). Location of S_y depends upon speed of stress.

KEY TO CURVES IN UPPER LEFT HAND CORNER FIG. 3..

Curve No. 1 A—Soft O. H. Steel, as rolled.
Curve No. 1 B—Soft O. H. Steel, oil tempered and annealed
Curve No. 1 C—Soft O. H. Steel, oil tempered.
Curve No. 2 A—Axle Steel, as rolled.
Curve No. 2 C—Axle Steel, oil tempered
Curve No. 3 A—O. H. Steel, forged disc.
Curve No. 3 B—O. H. Steel, forged disc, oil tempered and annealed.
Curve No. 3 C—O. H. Steel, forged disc, oil tempered.
Curve No. 4 B—Heavy Steel Casting, annealed
Curve No. 5 A—Cast Copper, annealed.
Curve No. 5 B—Cast Copper.
Curve No. 5 C—Hard Rolled Copper.
Curve No. 7 —Wrought Iron.
Curve No. 8 —Steel Casting, rim of small gear.
Curve No. 10 —Chrome Tungsten.
Curve No. 11 —Vanadium Steel.

Hooke's Law states that, within the elastic limit, the deformation produced is proportional to the stress.

Note.—Unless modified, the deduced formulas of mechanics apply only within the elastic limit. Beyond this the formulas are modified by experimental coefficients, as for instance, modulus of rupture.

Modulus of Elasticity (pounds per square inch) is the ratio of the increment of unit stress to increment of unit deformation within the elastic limit.

The Modulus of Elasticity in Tension, or Young's Modulus, E, is graphically measured by the slope of OP (Fig. 3); the compression modulus by the slope of OP'. The inverse values of E for several materials express the relative unit deformations of these materials under the same unit stress. *E is a measure of stiffness.*

Modulus of Elasticity in Shear, F, is the shearing unit stress divided by the angle of distortion expressed in radians. Theoretically, $F = n/2E(n+1)$; and when $n=3$, $F=3/8E$. (See Poisson's ratio.)

Bulk Modulus of Elasticity, B, is the ratio of unit stress, applied to all size faces of a cube, to the unit change of volume. Theoretically, $B=1/3En/(n-2)$; and when $n=3$, $B=E$.

Lateral Deformation, e', accompanies longitudinal deformation, e. *Poisson's Ratio*, m, is the ratio of e' to e. The inverse value of m is denoted by n, that is, $n = 1/m$.

Values of m given by Unwin are: Flint Glass, 0.244; Brass, 0.333; Copper, 0.333; Cast Iron, 0.270; Wrought Iron, 0.278; Steel, 0.303; Concrete, according to Talbot, 0.10.

Change of volume, under longitudinal deformation. l, d, b, = length, width and thickness; m = Poisson's ratio; s = unit deformation. Deformed volume

$$=(1+s)l(1-ms)b(1-ms)d=(1+s-2ms)lbd.$$

Fractional change of volume $=(1-2m)s$. When m is less than 1/2 the volume is increased in tension and decreased in compression. For steel, $(m=1/3)$, change of volume is about $\frac{1}{3000}$ part at the elastic limit.

A bar under stress does not at once assume the length due to its modulus of elasticity E. Deformation proceeds for days and weeks. These phenomena of *residual elasticity or elastic afterworking* do not seem to be of practical importance.

Resilience

Resilience, K, (inch-pound) is the potential *elastic energy* stored up in a deformed body. For instance, a falling weight compresses a spring; the stored energy, or resilience, of the material is a source of work and will produce return motion in the weight.

The amount of resilience is equal to the work required to deform the volume of material from zero stress to stress S.

For longitudinal deformation (Fig. 3), $P=$ load, $e=$ deformation, $S=$ unit stress, $E=$ modulus of elasticity, $l=$ length, $A=$ area cross section, $V=$ volume. Resilience $=$ work of deformation $=$ average force $\times$ deformation $=\frac{1}{2}Pe = \frac{1}{2}AS\, Sl/E$, or

$$K = V\tfrac{1}{2}S^2/E.$$

The resilience for any other kind of stress such as shearing, bending, torsion, is the volume times a constant C times one-half the square of the stress divided by the appropriate modulus of elasticity.

Resilience of solids of *varying section* cannot be expressed per unit of volume.

Resilience per Unit of Volume—K

S = longitudinal stress, Sv = shearing stress, E = tension modulus of elasticity, F = shearing modulus of elasticity.

1. Tension or Compression........	$\frac{1}{2}S^2/E$	SPRINGS.	
2. Shear........................	$\frac{1}{2}Sv^2/F$	Carriage......	$\frac{1}{6}S^2/E$
BEAMS, free ends. (Nos. 3–8.)		*Flat spiral* rect. section.	$\frac{1}{24}S^2/E$
3. Rectangular section, bent in arc of circle. No shear.	$\frac{1}{6}S^2/E$		
4. Rectangular section, bent in arc of circle. Circular section.	$\frac{1}{8}S^2/E$	*Helical* - axial load, circular wire.	$\frac{1}{4}Sv^2$
5. *Concentrated center load.* Rectangular cross section.	$\frac{1}{18}S^2/E$	*Helical* – axial twist.	$\frac{1}{8}Sv^2/F$
6. *Concentrated center load.* Circular cross section.	$\frac{1}{12}S^2/E$		
7. *Uniform load.* Rectangular cross section.			
8. I-beam section.................	$\frac{9}{32}S^2/E$		
TORSION. (9–10.)			
9. Solid, Circular.................	$\frac{1}{4}Sv^2/F$		
10. Hollow, Radii, R_2 and R_1.......	$\left\{(R_1^2+R_2^2)/R_1^2\right\}\frac{1}{4}Sv^2/F$		

Modulus of resilience, K_p (inch-pounds per cubic inch), or *unit resilience,* is the elastic energy stored up in a unit volume at the elastic limit. For longitudinal deformation K_p is graphically measured by the area OPP''. (Fig. 3.) $K_p = 1/2\ S^2/E$.

The unit resilience stored up at a stress *beyond* the *elastic limit* is measured by the area of the triangle $S''SS'$ (Fig. 3).

Unit rupture work, K_r, sometimes called *Ultimate Resilience,* is measured by the area of the stress-deformation diagram to rupture, $O\ P\ Y\ M\ R\ R'$, (Fig. 3).

$$K_r = 1/3\ e_u\,(S_y + 2S_m)\quad .\ .\ .\ .\ \text{approx.} \qquad (6)$$

Here e_u = the unit elongation at rupture.

For structural steel, for instance, $K_r = 1/3\ \frac{27}{100}\ (35{,}000 + 2 \times 60{,}000) = 13{,}950$ (inch-pounds per cubic inch).

CHAPTER IV

Material Stressed Beyond the Elastic Limit

Beyond elastic limit in tension S_p, ductile materials like steel enter a semi-plastic stage. The material stretches from Y to L (Fig. 3) without increase of stress, and the scale beam of the testing machine "*drops*," and the hard mill-scale falls from bar. Yielding proceeds from either shoulder of bar to center. Steel shows both S_p and S_y; cast iron, S_y but no S_p; wood and hardened steel, S_p, but no S_y.

The shape of the diagram from S_p to S_y depends upon *speed of stress*. Ewing found full line for fast, and dotted line, for very slow, speed (Fig. 3).

After L semi-plastic and semi-elastic deformations proceed. One or several contractions of cross section occur depending upon homogeneity of metal. The *maximum load* is reached at M (Fig. 3) when the metal at one of these contractions begins to flow. The contraction or "neck" proceeds until bar ruptures at R. The character of the metal changes under this excessive deformation, and, therefore, the actual stress on the ruptured section is not of practical importance, and is not observed.

Ultimate strength $S_m =$ maximum load/original area. The elongation and contraction after rupture are observed.

The load may be released at intervals to observe the set, OS'' (Fig. 3).

Fracture under tension indicates quality of material, but is influenced by speed and method of producing fracture, and by shape of test piece. A metal that is

tough and fibrous may appear crystalline if broken quickly at a nicked section. Contraction is greatest in tough and ductile, and least in brittle, materials. The *shape* of fracture is usually a center flat surface of failure in tension surrounded by a rim on which the metal shears. The extent of the rim is more pronounced when the ratio of shearing to tensile strength is less; is more developed in soft steels; becomes a complete cone in very soft materials; and vanishes in cast iron. The color, grain and shear of the fracture are insignificant. *Forms of fracture* in tension are shown in Fig. 4.

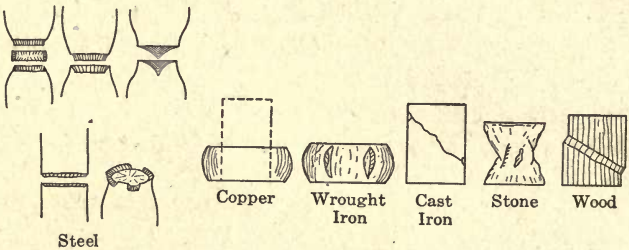


FIG. 4.—Characteristic fractures of materials in tension and compression.

Terms describing fracture are: silky, dull, granular, crystalline, fibrous.

FAILURE UNDER COMPRESSION depends on material, slenderness of specimen, and restraint at ends or sides. *Short blocks* of *brittle materials* in compression like cast iron, stone, cement, when unconfined at the sides, fail by sliding along inclined planes. The angle of these planes is a function of the shearing stress and of the coefficient of friction of the material. The theoretical angle of fracture, with the cross section is $\pi/4+\phi/2$ where ϕ is angle of repose of material. Internal cones, with their bases at the pressure heads of the testing machines, and pyramids, form in cylindrical and rectangular specimens respectively.

DUCTILE OR SOFT MATERIAL, like copper and soft steel, cannot be ruptured in compression. They bulge, increase in diameter under increasing stress, and finally become plastic at the *stress of fluidity*. That is, the deformation proceeds under a constant actual stress, per unit of deformed area, and is permanent.

The product of deformation and load (or normal stress) is then constant, and is expressed by a rectangular hyperbola. The outer portions of the stress strain diagram for lead and copper in Fig. 3 are approximately hyperbolic.

Unwin quotes the following values for pressure of fluidity in pounds per square inch. Mild steel, 112,000; Copper 54,000; Lead 1700. Experiment by Hatt gives for wrought iron, 76,000.

The strength of materials of medium ductility, like steel and wrought iron, in compression is generally to be taken at the yield point of the material.

Strength under compression depends on ratio of length to diameter of specimen.

The compressive strength of stone and concrete is about 10 times the tensile strength.

Fracture forms for several materials in compression are shown in Fig. 4.

Failure under pure shear is difficult to produce. The common form of test introduces bending stresses.

Ratio of shearing strength to compressive strength is not well determined. For concrete and brittle materials this ratio is reported to vary from 0.32 to 1.25.

The ultimate shearing strength of steel and iron is nearly three quarters of its tensile strength.

Hancock's Tests (Proc. Am. Soc. Test. Mat. 1908, p. 376) shows that the shearing elastic limit of steel and iron, determined in torsion, is 0.50 to 0.57 the proportional elastic limit in tension.

Failure of steel at or above the elastic limit is accompanied by appearance of *Hartmann's lines* on polished surfaces. These lines make an angle, with the axis of a tension bar, of 63° for soft steel, and 58° for annealed steel. They indicate a slippage along the cleavage planes of the crystals of the metal. Steel consists of an aggregation of crystalline grains separated by films or membranes of material of different compositions. Under this view failure in tension or compression is essentially a failure under shearing stress modified by internal friction.

CHAPTER V

Testing and Testing Machines

Technical qualities of materials may be grouped as:

Technological, having to do with manufacturing requirements, such as malleability, fusibility, forgeability, bending to shape.

Physical, such as specific gravity, plasticity, homogeneity, durability, structural characteristics, including fibrous, crystalline.

Mechanical properties examined in tests. These are listed in table below, together with criteria commonly used.

Quality	Service	Criteria	Example
Strength......	To carry dead load......	Ultimate strength	Piano wire.
Elasticity.....	To undergo deformation and return to shape.	Amount of elastic deformation	Rubber.
Resilience.....	To absorb energy without permanent deformation.	Modulus of resilience	Second growth hickory.
Stiffness......	To carry load without deformation.	Modulus of elasticity	Steel.
Hardness.....	To (a) withstand wear; (b) to resist penetration.	Scratch test; abrasion test Brinnel test.	Manganese steel.
Toughness....	Various conceptions; to endure large permanent deformations; to withstand large energy without rupture.	Various	Rivet steel; hickory wood.
Endurance....	To withstand repetition of stress with small shocks.	Endurance test	Vanadium steel.
Plasticity.....	The absence of elasticity.	Deform without return or rupture	Lead.

Testing Machines

Testing Machines must be accurate and sensitive.

Accuracy depends on correct lever proportioning, condition of knife edges, and stiffness of levers. (See Experiment A-2.)

For Sensitiveness knife edges should be of small radius, and straight, and stiff. Knife edge machines are usually more sensitive than necessary. Machines should be examined for clearance of levers from frame of machine. (See Experiment A-2.)

Specimens under test should not be subject to shocks or vibrations arising from the power elements of the machine, as for instance inertia of levers when specimen takes sudden elongation, or by the action of the pump in setting a body of liquid in motion.

Machines vary in capacity from wire tester of 600 lb. capacity to U. S. Govt. machines of 10,000,000 lb. capacity in compression. For ordinary use in a commercial laboratory, a machine of 200,000 lb. capacity is most suitable. For instruction of students a machine of 30,000 lb. capacity is most convenient. The present limit of screw-power scale beam machines for tension and compression is 1,000,000 lb.

The following table of large capacity testing machines is taken from an article by E. L. Lasier in the proceedings of the American Society of Testing Materials, 1913.

Static testing machines must provide proper means for (a) holding specimen, (b) applying load, and (c) weighing the load. Mechanical problems of gearing, absorbing shock, and oiling must be solved.

(a) Holding the Specimen

Tension and Compression.—It is important in testing a specimen in tension and compression, that the

LARGE CAPACITY TESTING MACHINES IN THE UNITED STATES AND ENGLAND

Machine	Type	Capacity, lb.		Power	Weighing device	Maximum length of specimen, ft.		Date of completion
		Tension	Compression			Tension	Compression	
Bureau of Standards, Pittsburgh, Pa.	Vertical	None	10,000,000	Hydraulic	Balance beam	None	25	1912
American Bridge Company, Ambridge, Pa.	Horizontal	4,000,000	None	Hydraulic	Mercury gage	42	None	1905
Phœnix Iron Company, Phœnixville, Pa.	Horizontal	2,800,000	2,800,000	Hydraulic	Mercury gage	50	55	1886
Bureau of Standards, Washington, D. C.	Horizontal	1,150,000	2,300,000	Hydraulic	Emery scale	33	33	1913
United States Steel Company, McKeesport, Pa.	Horizontal	1,200,000	800,000	Hydraulic	Mercury gage	40	32	....
Rensselaer Polytechnic Institute, Troy, N. Y.	Vertical	None	1,200,000	Hydraulic	Balance beam	None	3	1909
Bureau of Standards, Washington, D. C.	Vertical	None	1,000,000	Hydraulic	Pressure gage	None	9	1909
Department of Public Works, Philadelphia, Pa.	Vertical	None	1,000,000	Hydraulic	Pressure gage	None	3	....
Pennsylvania Railroad, Altoona, Pa.	Vertical	1,000,000	1,000,000	Screw	Balance beam	4	4	Unfinished
American Steel Foundries, Alliance, Ohio	Vertical	1,000,000	1,000,000	Screw	Balance beam	3	3	Unfinished
Watertown Arsenal, Watertown, Mass.	Horizontal	800,000	800,000	Hydraulic	Emery scale	20	26	1879
Lehigh University, South Bethlehem, Pa.	Vertical	800,000	800,000	Screw	Balance beam	24	24	1910
Joshua Buckton & Company, England	Horizontal	784,000	784,000	Hydraulic	Balance beam	20	5	....
Joshua Buckton & Company, England	Horizontal	672,000	672,000	Hydraulic	Balance beam	80	80	1909
Birmingham University, England	Horizontal	672,000	672,000	Hydraulic	Balance beam	33	30	1909
Bureau of Standards, Pittsburgh, Pa.	Vertical	600,000	600,000	Screw	Balance beam	24	30	....
Rensselaer Polytechnic Institute, Troy, N, Y.	Vertical	600,000	600,000	Screw	Balance beam	22	24	....
University of Illinois, Urbana, Ill.	Vertical	600,000	600,000	Screw	Balance beam	22	25	1905
University of Pennsylvania, Philadelphia, Pa.	Vertical	600,000	600,000	Screw	Balance beam	22	24	1908
University of Wisconsin, Madison, Wis.	Vertical	470,000	600,000	Hydraulic	Pressure gage	10	12	1907
Baltimore & Ohio Railroad	Vertical	600,000	600,000	Screw	Balance beam	22	24	....
American Steel & Wire Company, Pittsburgh, Pa.	Vertical	600,000	600,000	Screw	Balance beam	22	24	....
Pressed Steel Car Company, Pittsburgh, Pa.	Vertical	600,000	600,000	Screw	Balance beam	22	24	....

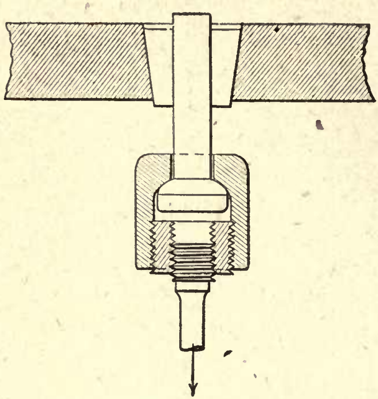


Fig. 5.—Universal joint for holding screw end test piece in tension.

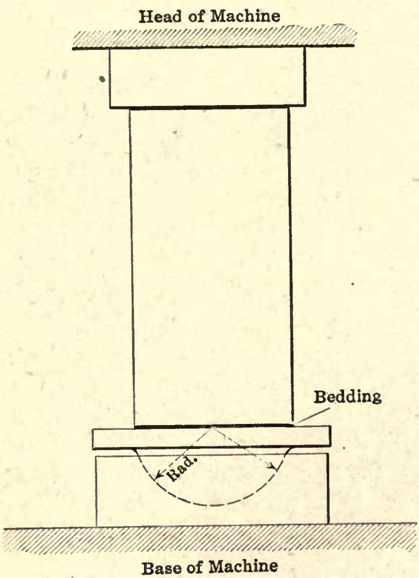


Fig. 6.—Spherical bearing plate and method of supporting test piece in compression.

load is applied as nearly as possible in the axis of the test piece. This implies that the specimen should be accurately centered in the testing machine. The common method of holding the test bar is by serrated wedges with flat face, which is suitable for ductile materials. For brittle materials, or short specimens, it is customary to use a spherical, or universal, joint between the specimen and the testing machine. These if correctly designed do away with bending and buckling in the specimen.

Fig. 5 and 6 illustrate the adaptation of the universal joint to tension and compression tests. Fig. 5 shows a

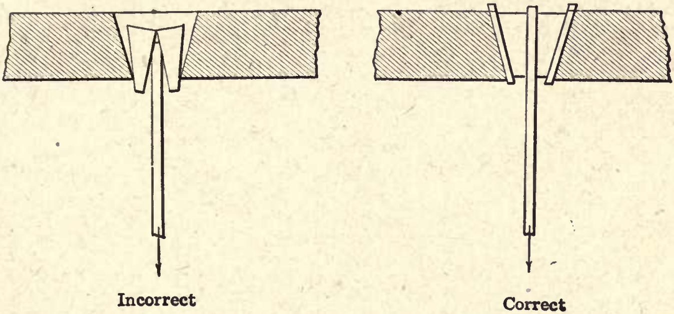


FIG. 7.—Method of gripping test specimen in tension.

convenient apparatus for gripping the standard short screw-end test piece and Fig. 6 shows the common method of supporting concrete or other like material in compression. A bedding of Plaster of Paris or blotting paper is used between the specimen and the surfaces of the machine, to give an even application of the load.

Fig. 7 indicates a correct and an incorrect way to grip a specimen in tension. The test piece should extend through the grips and these should have their full bearing over their entire length in the heads of the testing machine.

FLEXURE TESTS require freedom of specimen to bend

and rollers should be placed between supports and specimen. In case an auxiliary straining beam in used,

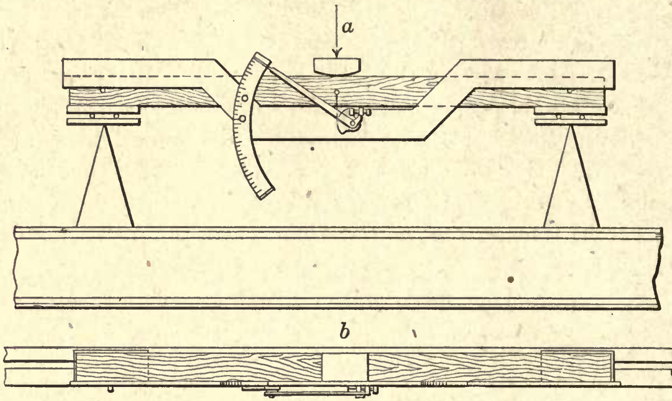


FIG. 8.—An apparatus for testing small beams in flexure.

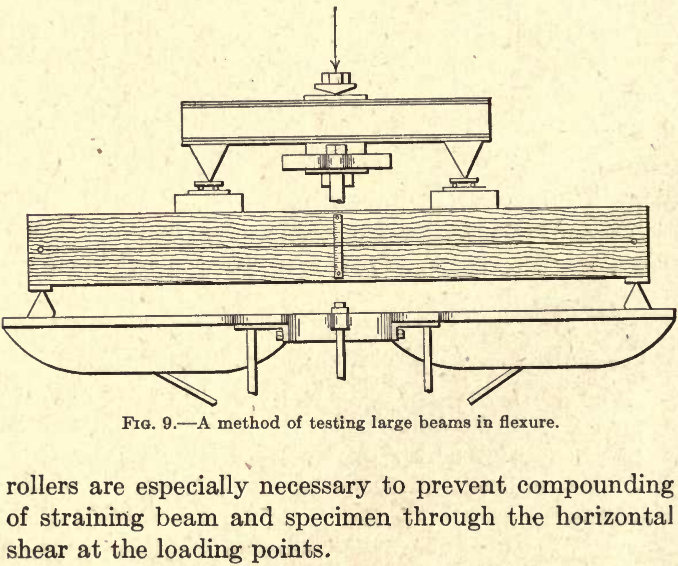


FIG. 9.—A method of testing large beams in flexure.

rollers are especially necessary to prevent compounding of straining beam and specimen through the horizontal shear at the loading points.

Figs. 8 and 9 show apparatus as used by the Forest Service in the tests of timber. In Fig. 8, the supporting beam is conveniently laid across the weighing table of a small capacity testing machine. The rollers and plates between supports and specimen prevent local failure and binding at the supports.

In testing large beams, Fig. 9, it is customary to apply the loads at the third points by means of an auxiliary

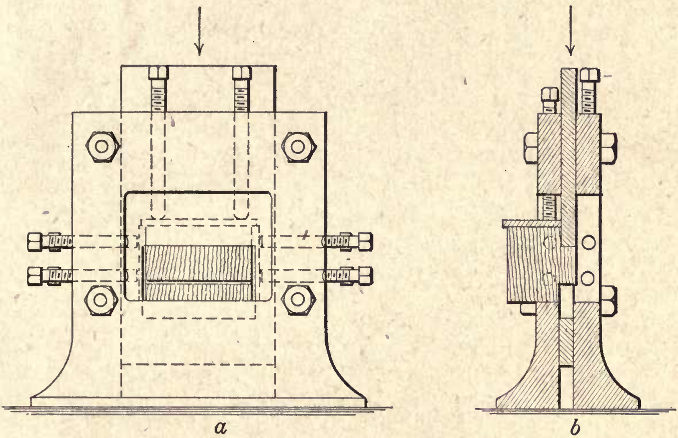


FIG. 10.—A shearing apparatus for wood.

beam with rollers and plates. The knife edge supports are, in this case, so constructed that they rock freely as the beam bends downward.

SHEAR TESTS.—Shearing shackles and tools should produce pure shear without bending. Fig. 10 shows a simple and reliable shearing tool for tests of timber. It is supported directly on the weighing table of the testing machine and the plunger comes in direct contact with the under side of the movable head.

(b) METHOD OF APPLYING THE LOAD

Loads are applied mainly by screw power (Olsen or Riehlé); or (2) hydraulic power (Emery or Amsler).

SCREW MACHINES.—American machines are commonly of screw power. Old screw machines should be examined

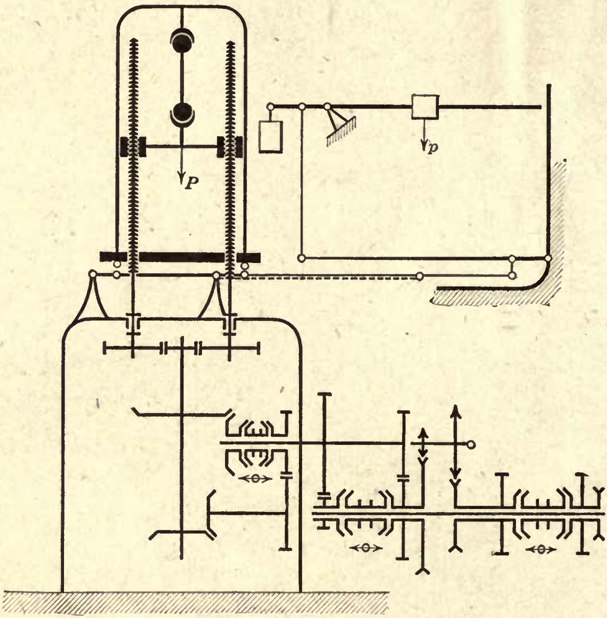


FIG. 11.—Diagrammatic view of a Richlé testing machine. (Modified from Marten's Handbook of Testing Materials.)

to see if the wear of the threads produces an oscillatory motion of the testing heads.

Fig. 11 represents by diagram a Riehlé testing machine. This is a two-screw machine. By rotation of the screws about their axes, the pulling head is moved up and down. Suitable gearing gives a variety of speeds in either direction.

Fig. 12 shows an Olsen machine. This is generally a four-screw machine, sometimes three. In this type, the pulling head is made to move up or down by the rotation of large geared nuts stationary in the base of the machine. Through these nuts pass the main screws to which is attached the pulling head. The screws do not turn on their axes.

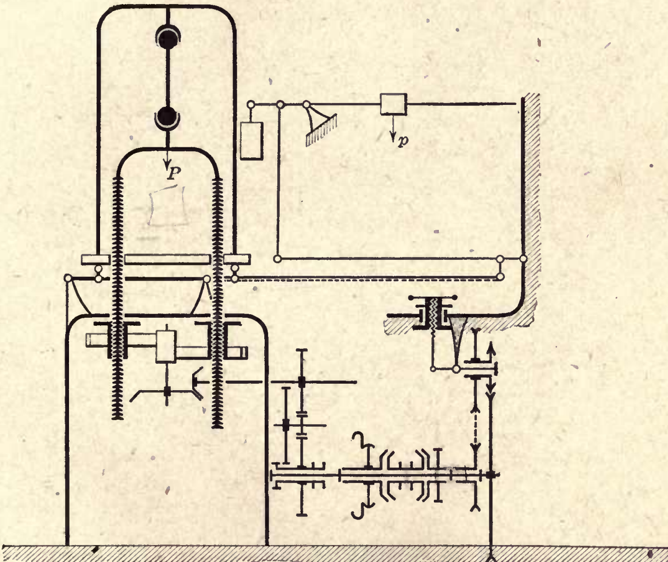


Fig. 12.—Diagrammatic view of an Olsen machine. (Modified from Marten's Handbook of Testing Materials.)

Hydraulic Machines.—Hydraulic machines, now becoming more popular, have many advantages in maintenance, steady loading, and in design of central power plant for laboratory. These sometimes involve friction of packing in cylinder, which is not important in large machines, and which is obviated in small machines (Amsler) by use of a floating piston and a viscous fluid

like castor oil. Proper provision should be made to hold a steady load.

Fig. 13 shows the Amsler machine of small capacity. As shown, the machine is equipped with a hand pump and a mercury column load indicating device. To the right is shown the more common pendulum method of indicating load.

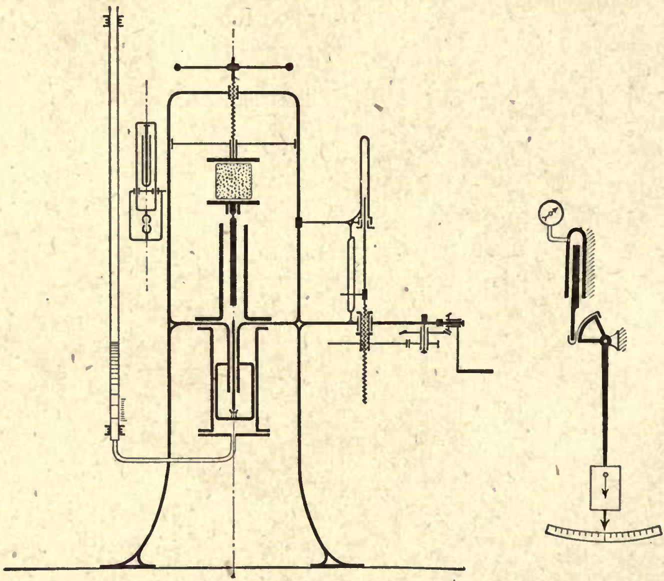


FIG. 13.—Diagram of Amsler testing machine. (From Wawrziniok.)

Fig. 14 is a diagrammatic sketch of a vertical Emery testing machine. The hydraulic cylinder *A* is fixed to the frame *D* of the machine by the main rods *SS*. The plunger *B* is attached to the gripping apparatus. The weighing system is independent of the power system.

IMPACT MACHINES.—Impact testing machines are (1) with vertical guides, or (2) of pendulum type. Provision

should be for measuring energy remaining in hammer after rupture of specimen. For this purpose, the hammer may fall on a spring (Fremont machine), or, a pencil attached to the hammer may write a curve velocity—displacement curve on a revolving drum (Turner machine). Method of release and hoist and mechanical details differ. Machines should be examined for: (a) fit of hammer in guides; friction; proportion of height of hammer to clear width between guides; proportion of weight of hammer to foundation; perfection of release; shape of striking edge. Hammer should deform specimen as a whole. Loss of energy at surface of impact and in foundation due to inertia of specimen should be small.

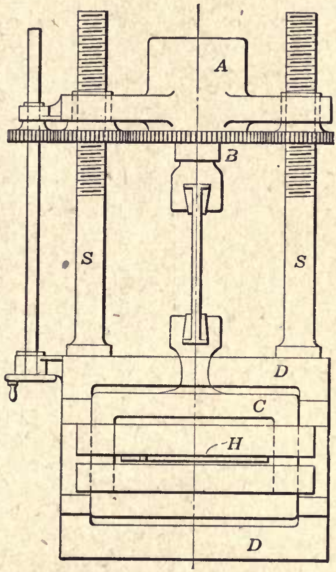


FIG. 14.—Diagram of a vertical Emery testing machine. (From Unwin.)

Fig. 15 illustrates the Turner vertical type of impact machine as used by the Forest Service in impact bending of small specimens. The pencil on the falling hammer makes a record on the revolving drum.

The drum record, Fig. 16, represents a test of a specimen broken in seven blows of increasing heights of hammer drop. The record gives the rebound heights and the deflection and set of the beam for each blow.

The drum record, Fig. 17, represents a test of a specimen broken in a single blow of the hammer. The drum

velocity is given by the tuning fork record T–T. The datum line O–O is the position of the hammer at instant of striking the specimen. The velocity of the hammer at that point may be obtained from the slope of the curve at the point of crossing. Distance up from the datum line represents free fall of the hammer. Distance

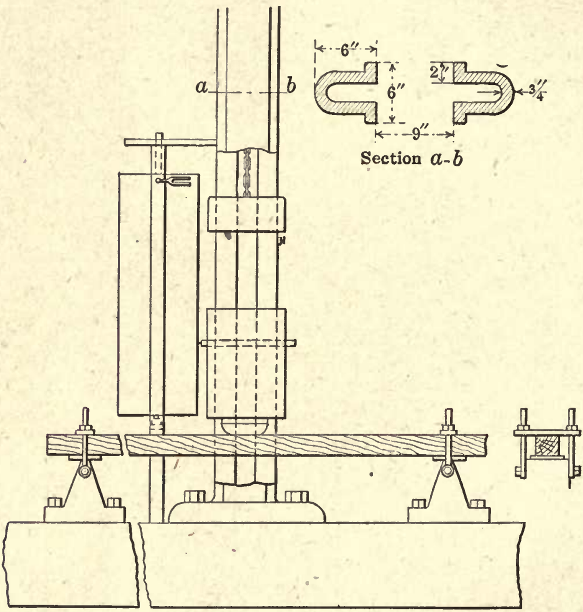


Fig. 15.—The Turner impact machine.

down from the datum line to point of rupture C represents restrained fall of the hammer and deformation of the specimen. Below the point of rupture, the hammer has free fall and the residual energy may be computed from the velocity as given by the curve slope.

Endurance Machines.—The ability of metals to withstand a rapid reversion of stress is an important

property. Heat-treated automobile or other machine parts are tested for this quality by means of the endurance testing machine as shown in Fig. 18.

The test piece *A*, accurately machined to size and shape, is rigidly gripped in the pulley *B*. The pulley is seated and free to turn in ball bearings in the frame *F*.

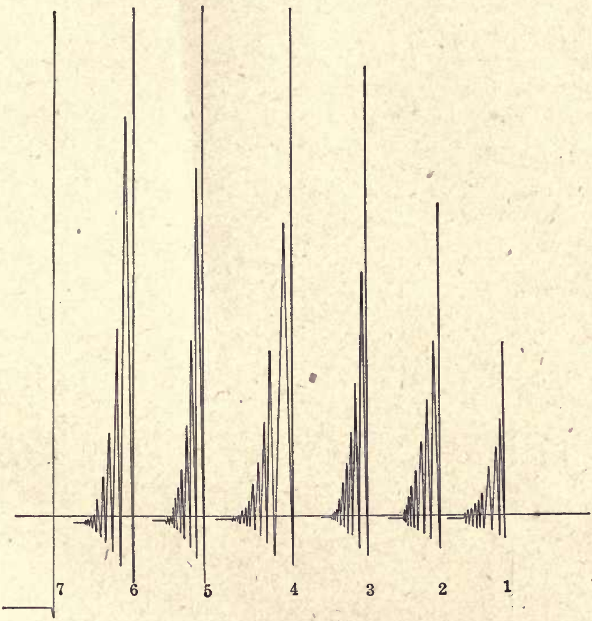


FIG. 16.—Drum record, Turner impact machine. Specimen broken by seven blows of hammer.

By means of the yokes *C–C* and their weight supporting standards, a load may be applied to each end of the test specimen. The pulley is made to rotate by belt connection to a motor. The speed of rotation is usually 1300 r.p.m. The stress in the top and bottom is alternately tension and compression in rapid succession.

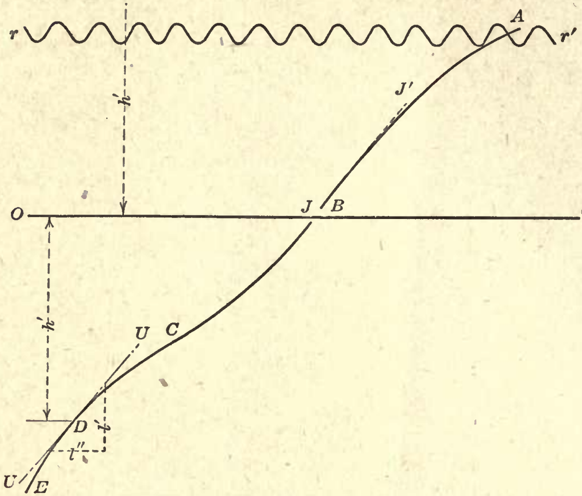


FIG. 17.—Drum record, Turner impact machine. Specimen broken in single blow.

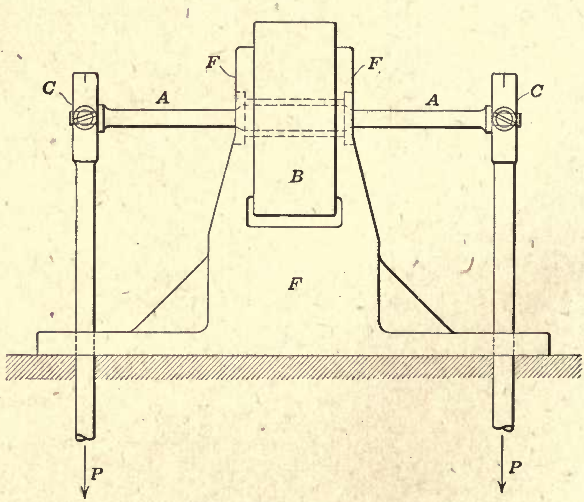


FIG. 18.—The White-Souther endurance testing machine.

Complete failure occurs at the edge of the fillets after a varying number of revolutions and at a stress below the elastic limit of the metal.

SPECIAL TEST.—*Hardness* is not well defined, nor uniformly measured. Unwin defines it as resistance to permanent or plastic deformation. In this definition it is distinguished from resistance to abrasion which is a compound of other qualities.

The best test for hardness is the Brinell Ball test. A hardened spherical ball (10 mm. diam.), is forced into a flat surface under a static pressure of 3000 kg., for 1/4 minute for steel and 1/2 minute for other hard metals. The specimen is 10 mm. thick and 35 mm. wide. Hardness = pressure / curved area of depression. A fixed ratio exists between hardness and tenacity of steels. Martens uses the depth of the impression. With balls 5 mm. in diameter the ratio of load to depth is constant within a depth range of 0.05 mm. The hardness number is the load necessary to indent material to 0.05 mm.

For instance, Brinell hardness number is as follows. Acid *Bessemer steel,* carbon 0.10, hardness number: rolled, 100; annealed, 96. *Basic Bessemer steel,* carbon 0.12, hardness number: rolled, 76; annealed, 81. Tensile strength of steel in kilograms, per square centimeter equals hardness number times 34.6.

A more recently perfected method for determinations of hardness is by means of the *Scleroscope.* In this instrument the height of rebound of a small diamond pointed tup is taken as a measure of the hardness of the surface upon which it is caused to fall. The height of drop is a fixed distance. The area of contact of the diamond point is so small that the metal upon which it strikes is stressed beyond the elastic limit.

For other tests see Unwin's Testing of Materials.

(c) WEIGHING MECHANISMS

(1) The most common type is the lever system. These are illustrated in Figs. 11 and 12, diagrammatic representations of the Olsen and Riehlé testing machines. All lever bearings and connections are hardened steel knife edges and plates. Load is indicated by the position of the poise *p* on the weighing beam.

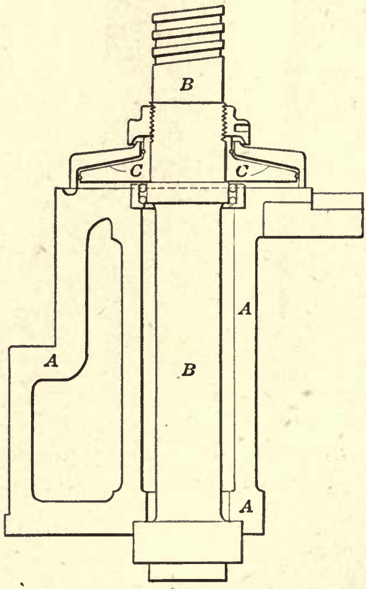


FIG. 19.

(2) A gage or manometric column indicates the pressure in the cylinder of hydraulic machines. Sometimes a pendulum lever is employed to serve the same purpose. These types are illustrated in Fig. 13 in the diagram of the Amsler machine.

(3) The pressure from the weighing table is transmitted to a hydraulic pad *H*, in Fig. 14, and thence to a mano-

metric column or as in the Emery machine, to a separate lever system the fulchra of which are elastic plates.

(4) A less common type is that in which the deformations of a portion of the frame of the machine are measured. The load is indicated by a measuring apparatus or by the change in volume of a hydraulic chamber which in turn is recorded on a fluid column. A diagrammatic view of this is shown in Fig. 19. The view shows one of the main rods *B–B* of the machine. This is fixed to the frame *A* of the machine. As the load comes on *B*, the deformation of *B* changes the volume of the chamber *C–C*, and is registered by a fluid column or other convenient means. The load value of the column is determined by calibration.

Extensometers and other Deformation Instruments

For the determinations of yield point of tension bars and deflection of beams, instruments reading to 0.01 in. are sufficient. But for the determination of elastic limit and modulus of elasticity and for many other purposes, deformation instruments reading to 0.0001 in. are required.

Extensometers may be classified:

(1) Micrometer screw, see Fig. 20. These are very reliable for experienced laboratory use but are seldom used for practical work. The contact of the micrometer points is best determined by means of an electric circuit and a telephone receiver in series.

(2) Roller dial (Johnson type), See Fig. 21. A simple type for laboratory use but unreliable on account of slippage at the roller. There is also error introduced by the wear of the roller. The readings are given direct on the dials.

(3) Roller mirror, see Fig. 22. This is very delicate and reliable, but unsuited to student or routine work of the laboratory. The instrument must be used where there is little vibration or jar.

(4) Lever type, examples of these are the Olsen, Ewing and Berry. The last of these is particularly well adapted to a large variety of practical work both in the

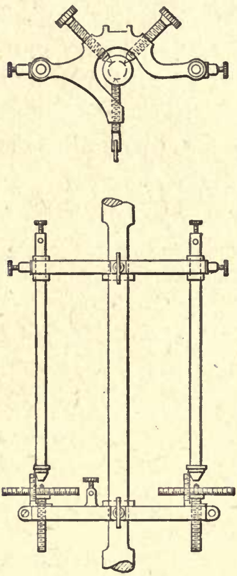


Fig. 20.—Yale-Riehlé extensometer.

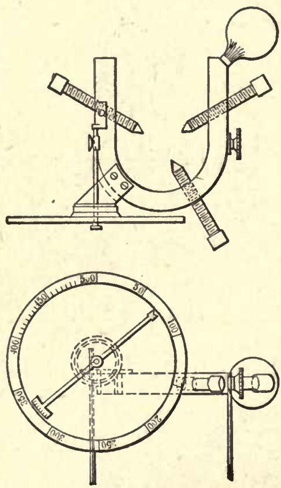


Fig. 21.—Johnson roller extensometer.

laboratory and in the field. In Fig. 23 is shown this instrument as made with contact points for use in reinforced concrete work and with adjustable gage length. The contact points are placed in small counter-bored holes in the test piece. In some cases, the instrument may be fixed and held in testing position throughout the loading, but generally it is removed after each reading is taken.

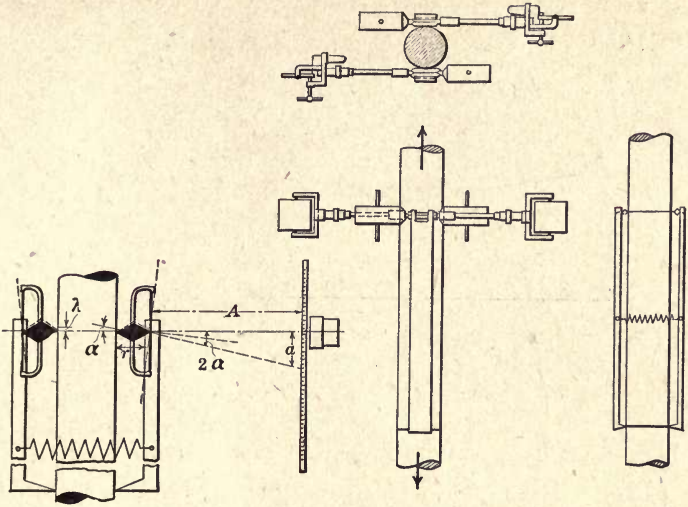


Fig. 22.—Marten's mirror extensometer.

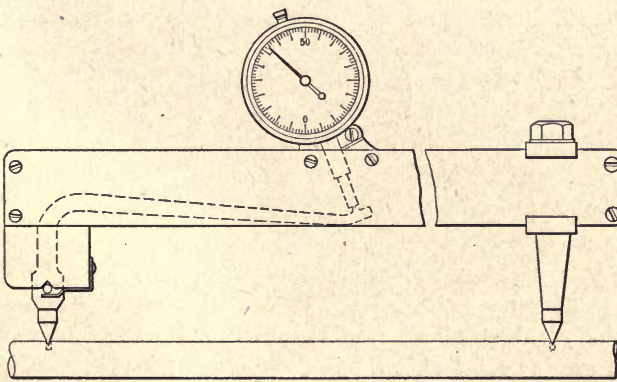


Fig. 23.—The Berry strain page.

In using the instrument, proper correction must be made for changes in temperature. The instrument reads

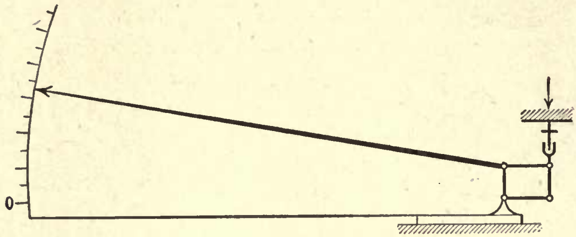


FIG. 24.—Diagrammatic representation of an Olsen deflection instrument.

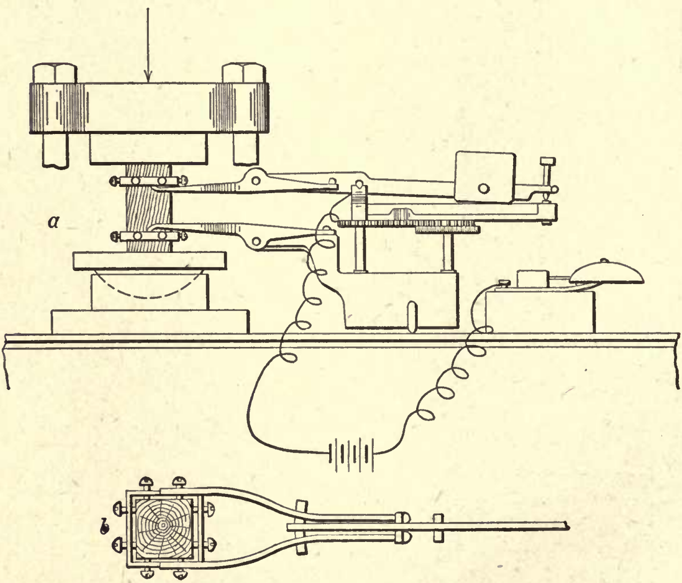


FIG. 25.—The Olsen compressometer.

directly to 0.0002 in. and closer by estimation of parts of a graduated division.

COMPRESSOMETERS.—The simplest type of compres-

someter is shown by diagram in Fig. 24; this is a good practical instrument for rough work. It reads directly to 0.01 in. and by estimation to 0.001 in.

Fig. 25 illustrates an instrument designed for closer more accurate determinations. This compressometer needs very careful handling for the best results. Better service may be accomplished by replacing the electric

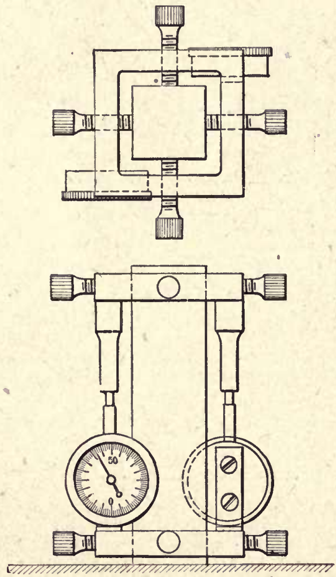


Fig. 26.—Author's compression instrument for short wood columns.

bell by a telephone receiver, to give the micrometer contact. The instrument reads directly to 0.0001 in.

A compressometer for short columns of timber which had been found very useful for student work by the authors, is shown in Fig. 26. Two yokes bearing Ames dials are attached to the specimen by four contact screws each. As the piece is deformed, the readings are given

on both sides by the Ames dials. These read direct to 0.001 in. and by estimation to 0.0001.

Autographic recording Apparatus.—A drum, Fig. 27, is fixed on the frame of the testing machine and put in gear with the specimen so that the rotation of the drum is proportional to the stretch of the specimen. A pencil in gear with the poise moves parallel to the axis of the drum. As the test proceeds, the diagram on the

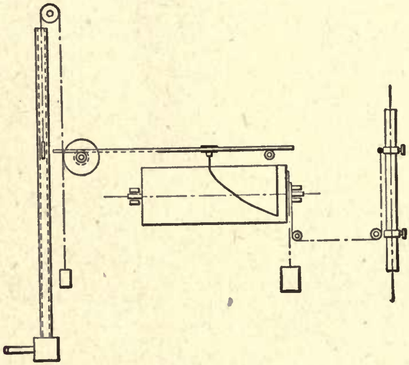


Fig. 27.—Autographic apparatus. (From Wawrziniok.)

drum has abscissæ of deformation and ordinates of load. In some types, the poise is replaced by a spring at the end of the scale beam. As the load is applied the scale beam rises and the spring measures the load. The rise of the beam actuates the pencil on the drum. This type yields delicate load measurements. A home-made simple autographic device is made of a steam-engine indicator on this plan.

Autographic recorders are not suitable for the delicate measurements for elastic constants and are of limited use.

CHAPTER VI

List of Experiments

Article 1. Testing Machines.

A-1. Study of Testing Machines.

A-2. Calibration of Testing Machines.

A-3. Calibration of Extensometers or other Measuring Device.

Article 2. Iron and Steel.

B-1. Commercial Tension Test of Wrought Iron and Steel.

B-2. Commercial Tension Test of Cast Iron or Cast Steel.

B-3. Autographic Tension Tests of Metals.

B-4. Tension Test of Iron or Steel with Extensometers.

B-5. Torsion Test of Iron or Steel.

B-6. Tension Test of a Wire Cable.

B-7. Compression Test of a Helical Spring.

B-8. Effect of Overstrain on Strength and Elasticity of Steel and Iron.

B-9. Flexure test of Cast Iron or Steel.

B-10. Flexure Test of Brake Beam.

B-11. Vibratory Tests of Stay Bolts.

Article 3. Tests of Wood.

C-1. Study and Identification of Woods.

C-2. Compression of Short Wood Blocks Parallel to Grain.

C-3. Compression of Wood Blocks Perpendicular to Grain.

C-4. Compression of Wood Columns.
C-5. Flexure of Small Wood Beams.
C-6. Flexure of Large Wood Beams.
C-7. Impact Tests of Wood.
C-8. Abrasion Tests of Wood.

Article 4. Tests of Cements.

D-1. Tests of Specific Gravity of Cements.
D-2. Fineness of Grinding.
D-3. Normal Consistency.
D-4. Time of Setting.
D-5. Soundness.
D-6. Strength of Cement and Cement Mortars in Tension.
D-7. Strength of Cement and Cement Mortars in Compression.

Article 5. Study of Aggregates.

E-1. Microscopic Examination of Sands, Gravels and Stones.
E-2. Determination of Amount and Character of Silt in Aggregates.
E-3. Specific Gravity of Sands, Gravels and Stones.
E-4. Determination of Voids in Aggregates.
E-5. Effect of Moisture on the Volume and Density of Aggregates.
E-6. Effect of Size of Particles on Density of Aggregates.
E-7. Relative Density of Sharp and Round Particles.
E-8. Sieve Analysis of Aggregates.

Article 6. Proportioning Mortars and Concretes.

E-9. Determination of Increase in Volume by Addition of a fine Material to a Coarser Material.
E-10. Proportioning Concrete by Method of Void Determinations.

E-11. Proportioning Concrete by Method of Sieve Analysis.

E-12. Volumetric Tests of Sands.

E-13. Proportioning Concrete by Method of Volumetric Synthesis.

Article 7. Tests of Concretes and Other Brittle Materials.

F-1. Strength of Mortars Made up of a Given Sand.

F-2. Compressive Strength of Concrete.

F-3. Test of Brittle Materials Determining Strength at First Crack and Ultimate.

F-4. Test of Brittle Materials Determining Strength and Elasticity.

F-5. Flexure Test of Reinforced Concrete Beams.

F-6. Tests of Concrete with Varying Gradations of Size of Aggregates.

Article 8. Tests of Road Materials.

G-1. Rattler Tests of Paving Bricks.

G-2. Absorption Test of Paving Brick.

G-3. Abrasion Test of Stone.

G-4. Cementation Test of Stone or Gravel.

G-5. Hardness of Stone as Determined in Dorry Test.

G-6. Impact Test of Stone, Standard Test for Toughness.

Experiments for Advanced Work

The following list of experiments represents subjects for special tests to be carried out by the student. Some of these may also be made the subject of thesis investigation.

Iron and Steel

Tension test of wire. Shearing tests of steel or iron. Tests of chains, hooks and rings. Tests of effect of

shop methods on strength of steel and iron. Flexure test of I-beams. Tests of car bolsters, side frames, etc. Tests of flat springs in bending. Tests of built-up columns. Tests of metals in rapid reversion of stresses using White-Souther machine. Tests of various forms of joints. Tests of hardness of metals using Scleroscope. Tests of alloy steels. Tests of steel plates.

Wood

Tension of various wood splices and joints. Indentation tests of wood. Wood in shear. Torsion of wood. Spike pulling tests of wood. Plate and washer bearing in wood. Tests of wood paving blocks. Tests of treated timbers.

Cement

Determination of weight per cubic foot of cement. Effect of fineness of grinding on properties of cement. Effect of varying amounts of gaging water. Effect of waterproofing methods upon strength and hardness. Tests for adulterants in cements. Effect of oils on properties of cements and cement mortars.

Concrete

Strength of concrete with clay admixtures. Tests of concrete columns, plain and reinforced. Concrete in shear. Bond of steel in concrete. Tests of concrete T-beams. Concrete arches. Tests of porosity and permeability of concrete. Electrolysis of steel in concrete. Machine vs. hand mixed concrete.

Brittle Materials

Compression tests, fire tests, freezing tests. Absorption tests. Tests of patent roofing, flooring or other building material.

CHAPTER VII

Instructions for Performing Experiments

Article 1

Testing Machines

Experiment A-1

STUDY OF TESTING MACHINES

In this experiment, the student becomes acquainted with various types of testing machines and gains skill in their operation.

MATERIALS.—No material to be tested.

SPECIAL APPARATUS.—Various types of testing machines as assigned. For each machine assigned, tabulate: capacity of machine; name of builder; vertical or horizontal; number of screws; drive, *i.e.*, belt, direct connected motor, hydraulic?

PROCEDURE.—

(a) Study operation of machine. Each student should become familiar with operation of machines as he is responsible for breakage due to ignorance and carelessness.

General rules for operators.

(1) Do not start machine into a continued motion without first ascertaining the direction and speed with which it will move. Extra precaution in this respect must be used if the movable head is near top or bottom of its range of movement.

(2) Do not start the machine with too sudden a

motion as there is danger of stripping a gear or throwing a belt.

(3) Do not reverse direction of motion or change speed without first stopping the machine.

(4) Stop and start the motion with the lever provided on the machine, *not* with the counter-shaft shifter.

(5) When leaving the machine *always* see that the motion is stopped and counter-shaft is shifted to loose pulley.

(b) Tabulate number and direction and value of the various speeds with which moving head can be moved.

(c) Study and sketch (on Form E or F cross-sectioe paper in ink) the weighing table with lever system and weighing device. Sketch the various positions of control and speed levers.

Discussion of Results.—In the report, answer the following questions:

(1) Why is there need for centering the specimen in the testing machine?

(a) With regard to effect on test piece.

(b) With regard to effect on machine.

(2) Why can not the friction drive and main clutch drive be used simultaneously? (This refers to Olsen type of machines only.)

(3) The slow speeds in the Olsen type of machine are obtained by a friction drive. In the Riehle type they are obtained by a system of gearing.

(a) Give advantages and disadvantages of the friction drive for slow speeds.

(b) Give advantages and disadvantages of the geared drive for slow speeds.

(4) How is shock arising from rupture of specimen absorbed in the machine?

(5) Where are the main wearing surfaces in the machine?

Experiment A-2

Calibration of Testing Machines

Testing machines should be calibrated at least once a year. This experiment will show the common methods of calibration.

I. Accuracy of machine over a part of its range of load.

The testing machine may be tested for accuracy by loading the weighing table with standard weights. The weights should be placed uniformly on the table and beam readings taken for the various weights applied.

This is the easiest and simplest manner of calibration of a testing machine but on account of the limited size of weighing table only a small part of the total capacity of the machine can be applied. However, the proportionality of the levers and weighing beam can be established and if the machine is correctly designed, the relation will hold constant for all loads. Auxiliary levers are also commonly used for this purpose.

II. Accuracy of a machine over a part or all of its range of load.

If the accuracy of the machine over its whole range is desired, a known load may be applied by a standard calibration bar whose modulus of elasticity has been accurately determined beforehand. The bar should be of sufficient strength so that the load desired should not stress it to or near the elastic limit. The bar should be carefully centered in the machine and gripped with the spherical bearing nut at the end. The length of the bar measured by the extensometer shall be sufficient that the

smallest division on extensometer will correspond to 100 lb., or less. The extensometer shall read deformations to 0.0001 in. or less.

III. Tests of sensitiveness of the machine at different loads.

Place in the machine a tension bar or a compression block of such size that the maximum load will not stress it to the elastic limit. Load the specimen to $\frac{1}{10}$, $\frac{1}{2}$, and $\frac{9}{10}$ the capacity of the machine. At each load, balance the weighing beam and place standard weights upon the weighing table. A weight $\frac{1}{250}$ of the load applied on the machine should produce a readable movement of the beam.

Experiment A-3

Calibration of Extensometers or Other Measuring Device

Case I.—Use a testing machine known to be accurate and a standard calibration bar whose modulus of elasticity is known. The extensometer to be calibrated is placed upon the bar in the usual manner and the modulus of elasticity determined in the usual way. The variation of the computed modulus from the correct modulus gives the error in the extensometer used.

Case II.—Using any bar and any machine determine the modulus with the extensometer to be calibrated and also with an extensometer which has previously been accurately calibrated. The variation in the modulus gives the error in the extensometer being calibrated. A convenient method is to use a bar of sufficient length to provide for both a standard extensometer and that to be tested. For greater refinement the extensometers may be interchanged in a second test.

Article 2

Iron and Steel

Experiment B-1

TENSION TEST OF IRON AND STEEL

The experiment is intended to represent the conditions obtaining in an ordinary commercial test with the exception that the speed of descent of the pulling head of the testing machine is much slower than customary in commercial laboratories. The experiment will determine the strength and ductility of the material.

References.—Standard Methods of Testing, in Year Books of Amer. Soc. for Testing Materials.

MATERIAL.—Bars of iron or steel as furnished.

SPECIAL APPARATUS.—Micrometer calipers, scale, dividers.

PROCEDURE.—1. Give specimen a number and record this.

2. With vernier or micrometer calipers determine the average dimensions of the cross section. Use average of three readings.

3. Lay off gage length of 8 in., each inch being marked by a light center punch mark.

4. Carefully balance the testing machine at zero of weighing beam after first loosening recoil nuts on weighing table. Then insert the test-piece in the wedges, being careful that the test-piece is centrally disposed in the axis of the machine, and that the ends of the test bar project slightly beyond the wedges. Tighten specimen in grips by applying a load of about 500 lb. Chalk a small area of the bar near the upper gage mark. *Before proceeding with the test allow the instructor to inspect the work.*

One student should insert one leg of a pair of dividers in the lower gage mark and scribe a line with the upper leg on the area previously chalked. Apply the load at a medium speed and operate the poise so as to keep the scale beam floating.

The operator with the dividers should continue to scribe the line and notify the operator at the poise when the width of the scribed line increases perceptibly due to sudden increase in the rate of stretching of the test bar under the load. At this time the beam may be expected to drop suddenly and remain down for an interval; also rough mill scale will fall from the specimen. This increase in elongation without a corresponding increase in load is the "yield point," or commercially, the "elastic limit." It is a point beyond the true elastic limit as obtained in experiment B-4.

During a further stretching of the bar the beam will again rise and should be kept floating up to the maximum load. At this maximum load the bar begins to neck in, the material becoming plastic at the point of the formation of the neck. Leave poise at maxmium load, do not attempt to get actual breaking load. Record in data sheet the load at yield point and the maximum load.

MEASUREMENTS AFTER TESTS.—Lay the broken ends of the bar together and determine the increase in elongation of the gage length. Measure the dimensions of the fractured area. Determine the rate of descent of the pulling head of the machine. Describe the appearance of the fracture (see page 16) and determine the distance from the extreme gage point.

CALCULATIONS.—Calculate the ultimate tensile strength.

Calculate the stress at yield point.

Calculate the per cent. of elongation in gage length and per cent. of contraction of area at the fracture.

In case the fracture is outside the middle third of the gage-length, the per cent of elongation is to be computed on the assumption that the elongation is symmetrical on each side of the neck. This should be noted in the report.

REPORT.—See instructions for writing reports, page 7. A form sheet for tabulation of original data and results will be supplied by instructor.

Experiment B-2

COMMERCIAL TENSION TESTS OF CAST IRON OR STEEL CASTINGS

References.—Specifications of Amer. Soc. for Testing Materials. Year Book, 1913.

The materials in this test are generally as follows:

CAST IRON.—Specimen in the rough, no machining; standard arbitration bar machined to standard size.

STEEL CASTING.—Standard machined test-piece using 2-in. gage length.

PROCEDURE.—The method of test of cast iron is same as for Experiment B-1 except that maximum load only is obtained. The method of test of steel castings is the same as for Experiment B-1 except that a gage length of 2 in. is used.

COMPUTATIONS.—Make all computations as in regular test B-1, for steel casting specimens. For cast-iron specimens compute tensile strength.

DISCUSSION OF RESULTS.—Compare results with specifications and show in tabular form.

Experiment B-3

AUTOGRAPHIC TENSION TESTS OF IRON OR STEEL

This experiment may be performed by the instructor in front of the class to exhibit method used in commercial

test B-1, and also by use of autographic diagram to show the general behavior of iron and steel when tested to rupture in tension.

Materials to be Tested.—The specimen should be a round bar of steel or iron.

Apparatus.—Besides the regular tension apparatus there should be the collars by which autographic apparatus is attached to specimen.

Procedure.—All dimensions and descriptions of specimens should be noted as in the regular tension test. After attaching the collars to the ends of the gage length, the specimen should be placed in the machine and a small initial load applied to hold it. Arrange the autographic apparatus so that the pencil is at the origin of diagram at zero load and zero stretch. Then apply the load continuously in a medium speed keeping the poise beam balanced. This may be done by the operator or by the mechanism in automatically balanced machines. Observe, and record the load at yield point as given by the diagram, by drop of the beam and scaling of the specimen. Observe the maximum load as given by the beam and diagram.

Ascertain the elongation as given by the diagram and by actual measurement of specimen.

Compute all results as obtained in regular commercial tension test.

Experiment B-4

Tension Test with Extensometer

In this experiment the strength and elastic properties of iron and steel in tension are determined.

References.—Standard Methods of Testing in Year Books of Amer. Soc. of Testing Materials.

MATERIAL.—Wrought iron or steel.

SPECIAL APPARATUS.—Extensometer.

NOTE.—The extensometers are delicate instruments and must be handled carefully. Any roughness of usage or lack of delicacy in manipulation will result in unsatisfactory diagrams. Be sure that the test bar is straight.

PROCEDURE.—Carefully measure and prepare each specimen as for regular tension test. Tighten specimen in grips by applying an initial load of 2000 lb. per square inch (the machine having been previously balanced). Apply and adjust the extensometer, noting the length between the contact points, and (*after having had the apparatus inspected by the instructor*) proceed with the test. Apply load in increments of 2000 lb. per square inch for steel and 1500 lb. per square inch for iron and measure the total elongation at each load increment. When a stress of 30,000 and 20,000 lb. per square inch for steel and iron respectively has been reached, apply loads in increments of one-half the former amount until, by the behavior of the beam, it is seen that the yield point is reached.

After reaching a sudden and large increase in elongation, remove the extensometer and apply load continuously until specimen is ruptured, keeping beam balanced. Record maximum load.

Construct a diagram with load in *pounds per square inch* as ordinates and elongation in *inches per inch* as abscissæ. Draw a *straight* line averaging the points up to the more rapid increase in elongation (the elastic limit), and, tangent to the straight line draw a smooth curve averaging the remaining points. Ordinarily, the straight line of plotted points will not pass through the origin. Draw through the origin a line parallel to the straight line of plotted points. This line represents the true relation between stress and strain. Mark the elas-

tic limit where the strain ceases to be proportional to stress.

CALCULATIONS.—Calculate stress at elastic limit, ultimate tensile strength, per cent elongation and contraction, modulus of elasticity, and modulus of elastic resilience.

The modulus of elasticity is the stress in pounds per square inch divided by the elongation in inches per inch at any point on the straight line through the origin. It is most convenient to select an abscissa of elongation of one part in 1000, and multiply the corresponding stress by 1000 to obtain the modulus of elasticity.

The modulus of elastic resilience is the amount of work done on each cubic inch of the specimen in deforming it to the elastic limit. It may be taken as the equivalent in inch-pounds of the area under the straight line up to elastic limit; or it may be calculated by formula.

REPORT.—The report shall contain (1) tension test blanks (furnished by instructor) properly filled out, (2) plotted curves with titles and scales shown, (3) ink copies of running log, (4) comparisons with standards.

Experiment B-5

EXPERIMENT IN TORSION

The object of this experiment is to study the behavior of materials under torsion, and to obtain such data as will enable the shearing strength of the material and its modulus of elasticity in shear to be computed.

MATERIAL.—The material may be steel, iron, wood, or other material.

SPECIAL APPARATUS.—Torsion Troptometer.

PROCEDURE.—Carefully measure the dimensions of the cross-section and lay off gage length of 8 in. Then adjust the specimen in the heads of the machine, being

careful that the specimen is fixed in the axis of rotation of the machine. Then apply the torsion troptometer to the specimen and adjust the clamps of the latter so that the center of the circle of the graduated arc will be in the axis of the machine. Measure the distance from the axis of the specimen out to the graduated arc. Apply a small initial moment of about 100 in.-lb. and set to zero the graduated arc, and also the permanent scale on the twisting head of the machine.

Experiment.—Apply the loads by increment of 200 in.-lb. Read on the graduated arc the movement of the pointer in inches for each increment. When the increase in the angle of torsion is found to be rapid, the elastic limit has been reached. The graduated arc and index should then be removed.

If only the elastic properties of materials are to be determined the specimen may be removed. Ordinarily the tests are to be continued until the specimen is ruptured. Read load every 180° turn. The whole angle of the twist is read from the fixed scale on the movable head of the machine. The scale beam should be kept balanced and the maximum load determined.

Curves.—Plot diagrams to suitable scales with the twisting moment in inch-pounds as ordinates and the angle of twist in degrees as abscissæ. One of these curves will be drawn with the magnified abscissa and will show the points up to the elastic limit. The other curve will be on a small scale and will show the angle-moment diagram up to the rupture. As in other experiments, the straight line portion in the beginning should pass through the origin. If it does not, a straight line parallel to the straight line passing through the plotted points should be drawn through the origin and terminating at the elastic limit. Mark the points corresponding to the elastic limit and maximum load on the curve.

Calculations.—Compute (1) the shearing stress developed at the elastic limit and the maximum load, using formula. (2) Calculate the modulus of elasticity in shear. (3) Compute also the elastic resilience per cubic inch.

Use the coordinates of any point on the corrected curve of the magnified scale.

Report.—The report will contain (1) torsion test blank, (2) plotted curves on coordinate paper, (3) an ink copy of the running log and loads of deformation, (4) comparisons with standard.

Experiment B-6

Test of Wire Cable

The purpose of this test is to determine the strength of a wire cable by testing the separate wires.

References—Johnson's Materials of Construction, page 691.

Material.—One piece of a wire cable about one foot long. Be sure it is a full strand.

Procedure.—Note strands in rope, number of turns per foot in strand, number of turns per foot in cable. Untwist wires of strand, note number of wire, determine the diameter in two places on each. Test each wire to rupture. Note breaking load. Calculate. (1). Tensile strength of wires in pounds per square inch. (2). Strength of cable. (3). Would cable be as strong as the sum of all the strengths of the individual wires? Why?

Report above items and submit in regular form.

Note.—Tabulate the number of wires whose strengths are within 5 per cent., 10 per cent., 15 per cent., 20 per cent., 25 per cent. of average strength, etc.

Experiment B-7

Compression of Helical Spring

References.—Unwin's Strength of Materials.

Object.—A helical spring under load is a case of torsion. Springs are tested to determine their capacity and travel. The modulus of elasticity in shear and the resilience of the springs may be computed.

Material.—Two helical springs.

Apparatus.—Deflection instrument.

Procedure.—Measure height of spring, diameter of coil, diameter of wire and number of free turns. Place spring in testing machine as for compression. Apply 100 lb. initial load; adjust the deflectometer. The load is applied by increments of—— pounds taking travel or compression at each load.

Plot load-deformation curve, and energy-travel curve.

Calculations.—(1). Load at instant spring becomes solid (Maximum load). (2). Fiber stress in shearing at maximum. (3). Resilience per cubic inch at maximum. (4). Modulus of elasticity in shear.

Report should cover above elements and appear in general form.

Experiment B-8

Effect of Overstrain on Yield Point of Steel

Reference.—Burr's Elasticity and Resistance of Engineering Materials.

Material.—Steel bar about 18 in. long.

Apparatus.—Autographic extensometer.

Procedure.—Measure the dimension of the test piece and lay off a gage length of 8 in., marking each inch with a light prick punch mark. Fasten into machine, let

automatic apparatus draw axis on sheet. Calculate probable elastic limit. Apply load to about two-thirds of this amount, keeping beam carefully balanced. Release the load slowly, noting the path taken by the pencil point. Apply load again until past yield point. Release as before. Repeat three or four times. Take all measurements as in B-3. For accurate work, a regular extensometer must be used. Note slope of curves.

Report.—Report should include analysis and discussion of results.

Experiment B–9

Flexure Test of Cast Iron or Steel

This experiment is intended to show method of testing cast iron or steel in flexure and to give data for the computation of transverse strength.

Material.—A round, or rectangular bar of iron or steel of sufficient length to give a space of at least 10 in.

The "Arbitration Bar" of cast iron is a bar 1 1/4 in. in diameter and 15 in. long. The bars are in the rough and molded with special treatment.

Special Apparatus.—A deflectometer reading to 0.001 in.

Procedure.—Arrange testing machine for transverse test with supporting knife edges at least 10 in. apart. Compute breaking load (using table of strengths in appendix) and use an increment of load equal to 1-15 of the breaking load. Measure deflection at center of span for each increment of load.

Results and Conclusions.—The report should be written in usual form and contain a comparison with specifications or other reliable data. Show load-deflection curve.

Experiment B-10

Flexure Test of Brake Beam

Brake beams are required to pass certain specifications of the Master Car Builders' Association.

Reference.—Report of Master Car Builders' Association, April, 1906.

Material.—Any brake beam complying with the M. C. B. Standard Specifications for dimensions.

"The beams shall be equipped with suitable heads and shoes, and the shoes placed in contact with castings representing the tread of the wheel. When mounted in this manner, the load shall be applied to the fulcrum in the normal line of pull. As a preliminary to the test, a load of 6000 lb. shall be applied and released, after which observations for records shall be taken," consisting of readings of deflections at each load and set following each load.

Plot load-deformation curve.

Results.—Compare with M. C. B. specifications.

See general form of report.

Experiment B-11

Vibration Test of Staybolt Iron

Staybolt iron should pass certain vibratory tests.

Reference.—Proceeding of American Society for Testing Materials, Volume 5, page 134. Also Year Book of American Society for Testing Materials.

Material.—Threaded staybolt iron of 7/8 in. to 1 1/8 in. in diameter.

Apparatus.—Olsen vibratory testing machine.

Method.—A threaded specimen, fixed at one end, has the other end moved in a circular path while stressed with

a tensile load of 4000 lb. The circle described shall have a radius of 3/32 in. at a point 8 in. from end of specimen." The speed of the machine shall be about 100 r.p.m.

RESULTS.—Compare results with specifications of the American Society for Testing Materials. See 1911 Year Book.

See general form of report.

Article 3

Tests of Wood

Experiment C-1

INSTRUCTIONS FOR LABORATORY EXERCISE FOR THE IDENTIFICATION OF WOODS

PURPOSE.—The purpose of this experiment is practice in identification of timbers by appearance.

MATERIAL.—The material will consist of specimens exhibited in the Laboratory for Testing Materials, numbered in consecutive numbers, including the common species of soft and hard woods; a key to these; Bulletin No. 10 of the Forest Service; and a pamphlet entitled "Trees of the United States Important in Forestry."

OUTLINE OF WORK.

(1) Take the key to these woods and examine each in turn with reference to the material in the text mentioned above. Make notes concerning (a), in the hardness of the material, (b), the character of the grain as shown on the cross section, (c), the kind and distribution of pores, (d), the relative proportion of spring and summer wood in the rings, (e), color and appearance of the surface, together with whatever other external features will aid in the identification. Additional short sections of the specimens on exhibit will be found hanging behind the

large specimens. The large specimens should not be damaged, but the smaller duplicates may be cut with a jack knife to determine their working qualities.

After this work is performed, the instructor will test the knowledge of the student by asking him to identify selected specimens of the woods.

REPORT.—Report will describe six selected species, together with drawings of the structure of the wood as seen through the magnifying glass. The uses and sources of supply of the wood will also be described.

SIX SELECTED SPECIMENS

I. White Oak.
II. Red Oak.
III. Yellow Pine (Longleaf).
IV. White Pine.
V. White Hickory.
VI. Hard Maple.

Experiment C-2

COMPRESSION OF SHORT WOOD BLOCKS PARALLEL TO GRAIN

This experiment should be preceded by the flexure of short beams C-5 and the material for this test taken from ends of short beams used in C-5.

MATERIALS TO BE TESTED.—The blocks to be tested are to be about 2 in.×2 in.×8 in. They should be surfaced four sides with the ends squared and smooth cut.

APPARATUS.—A compressometer reading to at least 1/1000 in. Collars, by means of which compressometer is attached to specimen. See Fig. 26.

PROCEDURE.—Ascertain and record the following data: (a) Kind of wood. (b) Per cent. of heart and sap wood. (c) Per cent. of summer wood. (d) Annual rings per

radial inch. (e) Dimensions of the block. (f) Note defects.

Lay off the gage length, usually 6 in., on specimen and attach the collars at the ends of gage length. Place in the machine on the spherical bearing plate and center.

Apply initial load equal to the first increment (generally 1000 lb. for the hard woods). After adjusting the compressometer to a zero reading apply the load by increments until the elastic limit has been reached. This is seen from the increased increments of deformation at that point. Take a reading for at least two loads beyond the elastic limit.

Remove the compressometer and loosen the collars and then, applying the load continuously in the slow speed, obtain the maximum load. Carry the loading far enough to develop the character of fracture.

Computations.—Plot a diagram for each specimen with load in pounds as ordinates and deformation in inches as abscissæ. If the straight portion of the curve below the elastic limit does not pass through the origin, draw a parallel straight line through the origin. The load at elastic limit should be taken from this curve.

Compute.—(a) Unit compressive strength at elastic limit. (b) Compressive strength at maximum load. (c) Modulus of elasticity. (d) Modulus of elastic resilience.

The report should show sketches of fractured specimens.

Experiment C-3

Compression of Wood Perpendicular to Grain

This experiment is to be preceded by C-5 and the material for this test is to be taken from ends of beams used in C-5.

MATERIALS.—Blocks about 2 in.×2 in.×8 in. finished four sides.

APPARATUS.—A compressometer reading to 1/1000 in. A rectangular finished bar of cast iron 1 in.×2 in. ×4 in.

PROCEDURE.—Ascertain and record the following data: (a) Kind of wood. (b) Per cent. of heart and sap. (c) Per cent. of summer wood. (d) Annual rings per inch. (e) Dimensions of the block.

Place the specimen in the machine flatwise and center. The cast-iron block should be placed on the specimen flatwise and long axis perpendicular to long axis of specimen.

Apply the load continuously directly upon the cast-iron block, taking readings of compressions for increments of load as follows: 800 lb. for heart hard woods, and 400 lb. for sap hard woods and 200 lb. for soft woods.

The loading should be carried to the elastic limit of the specimen. This may be seen from the increased increments of deformation at that point. Do not try to obtain maximum load as there is none in specimens of this size across grain.

CONPUTATIONS.—Plot a diagram for each specimen with load in pounds as ordinates and deformations in inches as abscissæ. The load at elastic limit should be taken from this curve. Compute unit compressive strength at elastic limit.

Experiment C-4

TESTS OF WOOD COLUMNS

In this experiment, the behavior of the wood under column action may be learned together with constants of strength of colunms.

Material.—Small wood columns of any species. They should be dressed on four sides, true to dimensions and have a slenderness ratio between 20 and 150. At least two columns of each species of wood of different slenderness ratios should be available for test.

Procedure.—Ascertain and record all data as in Experiment C-2.

Stretch a wire along the neutral axis of the narrow side of column. Great care must be taken in centering specimen in the machine. Apply small initial load and then determine zero reading of deflector at center of column.

Apply load in increments of 1000 lb. per square inch, taking readings of deformation for each instrument.

The condition at ends may be one of the two cases: flat ends, hinged ends. Test in each condition of ends, two columns of different slenderness ratios.

Calculations.—Cpmpute values of S and ϕ for each species of wood and for each condition of ends. Use Rankines formula.

Experiment C-5

Flexure Test of Small Wood Beams

This experiment gives the strength and elasticity of woods as shown in tests of small specimens.

Materials.—Two or more pieces of wood of oak, pine or other species. The size is about 2 in. $\times$2 in. $\times$ 28 in. The specimens are finished on four sides.

Apparatus.—Deflection Instrument reading to 0.0001 in.

Procedure.—Ascertain and record the following data: (a) Kind of wood. (b) Per cent. heart wood and sap wood. (c) Per cent. summer wood. (d) Annual rings per radial inch. (e) Dimensions of piece. (f) Weight

of specimen in grams. (g) Note defects such as knots, season checks, rot, etc.

On one side of specimen mark the neutral axis and span-length and mid-span lines. The span to be used is 26 in.

Place the beam upon the knife edge supports, using two short iron plates with rollers between, to prevent local crushing of the wood and binding between the supports. Apply an initial load of 100 lb. and adjust deflection instrument to read zero. See Fig. 8.

Note.—Common methods of measuring deflections are as follows:

(a) Place a deflectometer on base of machine under center of beam. (Fig. 24.)

(b) Hang a special deflectometer on pins or tacks in the neutral axis over supports and attach the wire of needle to tack in neutral axis at mid-span. See that wire is vertical. (Fig. 8.)

(c) Stretch a wire between tacks over supports and scale attached to beam at mid-span. A mirror or polished scale should be used so that image of wire may be seen, thus avoiding parallax. (Fig. 9.)

Of these methods, the second is the most accurate but the first and last may be used in certain work. Apply the load continuously at a slow speed and take readings of deflection for increments of 100 lb. load. If care is exercised, in keeping the beam balanced near the point of failure, it will be possible to read the correct load and deflection at failure even though this does not occur at one of the regular load increments. After obtaining the maximum load, carry the loading only far enough to develop the point and character of fracture.

Sketch and describe fractures.

Moisture Content of Specimen.—Cut from the

specimen near the point of failure a disk about 1 in. in thickness. Trim off all loose wood and weigh on sensative balances. This moisture disk is to be oven-dried and again weighed. The loss in weight expressed as a per cent. of dry weight gives the per cent. of moisture in beam.

For Tests in Compression.—Saw from the beam already tested, two test pieces 8 in. in length to be used in Experiments C-2 and C-3.

Computations.—Plot a diagram with load in pounds as ordinates and deformation in inches as abscissæ. Draw the correction curve through the origin, if necessary. The load at elastic limit is taken from this curve.

Compute.—(a) Fiber stress at elastic limit. (b) Modulus of Rupture. (Fiber stress at maximum load.) (c) Modulus of Elasticity. (Use corrected deflections.) (d) Elastic Resilience per cubic inch. (e) Rupture work per cubic inch. (f) Per cent. moisture. (g) Specific gravity.

Discussion of Results.—Compare results with average of other tests upon same and different kinds of timber.

Experiment C-6

Flexure Test of Large Wood Beans

The strength and elacticity of timber in full size specimens are determined in this test.

References.—Circular No. 38, of Forest Service.

Material.—Full size specimens of any wood in which span length does not exceed 16 ft. The specimens may be finished or in the rough but should be sawed true to ize and squared.

Procedure.—Ascertain and record all data as in Experiment C-5. The method of testing is the same as in

C-5 except that the load is applied at the third points, to approach as nearly as possible to conditions of uniform loading. Moisture content is obtained as in C-5.

Computations.—Make all computations as in Experiment C-5.

Discussion of Results.—Compare results with average of other tests upon same and different kinds of timber.

Experiment C-7.

Impact Test of Wooden Beams

In determining the relative brittleness of different timbers, tests in impact bending will be made.

Reference.—Circular no. 38, Forest Service.

Material.—Two 2 in.×2 in.×30 in. sticks. Any timber.

Special Apparatus.—Impact machine.

Procedure.—The resistance of a specimen of wood under impact is usually determined by dropping a given weight from successively increasing heights. The successive amounts of deformation and set of the specimen and rebound of the hammer are recorded on the drum. The elastic strength of the specimen is fixed at that limit at which the deflection suddenly increases. At this limit a sudden increase in the set of the specimen, as well as a maximum amount of rebound of the hammer, usually occurs.

In making the test the hammer is allowed to rest upon the upper surface of the specimen, and a zero or datum line is drawn on the drum. The deflection under the dead load of the hammer is obtained from a static cross-bending test of similar material. A corrected zero line can thus be drawn. Then blows of a weight dropped from increas-

ing heights are delivered to the specimen, and records taken on the drum. A sample record is seen in Fig. 16.

The height of the drop at which any rupture of the specimen occurs is noted, together with other phenomena of test. Sample log sheets and calculations will be found in the Appendix of Circular 38, Forest Service.

The machine is calibrated in advance to determine the proportion of the height of fall which is not effective because of friction and lag of magnet.

Occasionally the beam is ruptured under a single blow of the hammer falling from a height greater than that necessary to rupture the specimen. In this case the residual energy resident in the hammer, after rupture of the specimen, must be determined in order that the amount of energy used up in rupturing the specimen may be known.

The zero or datum line is determined as before, the hammer is released from a height greater than that necessary to rupture the specimen, and a record is taken of the circumstances of the impact. The tuning fork must be held on the drum during impact. A sample record is shown in Fig. 17.

Calculations.—Determine rupture-work, height of drop at elastic limit and maximum. Specific gravity, etc.

Experiment C-8

Abrasion Test of Wood

Purpose.—The purpose of this test is to determine the relative wearing ability of different woods.

Material.—2 in.×2 in.×2 in. cubes of wood, three specimens, and three standard maple blocks.

Apparatus.—Dorry abrasion machine for wood.

METHODS.—Measure blocks carefully at the four corners. Place blocks in machine in one of the six possible ways (see instructor). The standard maple block and test specimens must be exactly the same and wear against the same portion of the paper. Run the machine at 68 r.p.m. until the standard or test specimen wears down about 3/4 in., or, in time units, 15 minutes.

RESULTS.—Measure again at four corners. Calculate volume worn away and per cent. of wear of test specimen in relation to that of standard specimen.

Compare with other tests.

CAUTION.—Take care that weight of the holder is always on both pieces.

Article 4

Tests of Cements

METHODS FOR TESTING CEMENT[1]*

CONDENSED FOR USE IN SPECIFICATIONS

1. SAMPLING

Cement in barrels shall be sampled through a hole made in the head, or in one of the staves midway between the heads, by means of an auger or a sampling iron similar to that used by sugar inspectors; if in bags, the sample shall be taken from surface to center. Cement in bins shall be sampled in such a manner as to represent fairly the contents of the bin. The number of samples taken shall be as directed by the engineer, who will determine whether the samples shall be tested separately or mixed.

[1] Acccmpanying Final Report of Special Committee on Uniform Tests of Cement of the American Society of Civil Engineers, dated January 17, 1912.

* Authorized reprint from Proc. 1912, Amer. Soc. for Testing Materials.

The samples shall be passed through a sieve having twenty meshes per linear inch, in order to break up lumps and remove foreign material.

2. Chemical Analysis

The methods to be followed, except for determining the loss on ignition should be those proposed by the Committee on Uniformity in the Analysis of Materials for the Portland Cement Industry, reported in the *Journal of the Society for Chemical Industry*, Vol. 21, p. 12, 1902, and published in *Engineering News*, Vol. 50, p. 60, 1903, and in *Engineering Record*, Vol. 48, p. 49, 1903, and in addition thereto the following:

(a) The insoluble residue may be determined as follows: To a 1-grm. sample of the cement are added 30 c.c. of water and 10 c.c. of concentrated hydrochloric acid, and then warmed until effervescence ceases, and digested on a steam bath until dissolved. The residue is filtered, washed with hot water, and the filter paper and contents digested on the steam bath in a 5-per cent. solution of sodium carbonate. This residue is filtered, washed with hot water, then with hot hydrochloric acid, and finally with hot water, and then ignited at a red heat and weighed. The quantity so obtained is the insoluble residue.

(b) The loss on ignition shall be determined in the following manner: One-half gram of cement is heated in a weighed platinum crucible, with cover, for 5 minutes with a Bunsen burner (starting with a low flame and gradually increasing to its full height) and then heated for 15 minutes with a blast lamp; the difference between the weight after cooling and the original weight is the loss on ignition. The temperature should not exceed 900° C., or a low red heat; the ignition should preferably be made in a muffle.

3. Specific Gravity

The determination of specific gravity shall be made with a standardized Le Chatelier apparatus. This consists of a flask (D), Fig. 1, page 308, Year Book 1912, Amer. Soc. for Testing Materials, of about 120 c.c. capacity, the neck of which is about 20 cm. long; in the middle of this neck is a bulb (C), above and below which are two marks (F) and (E); the volume between these two marks is 20 c.c. The neck has a diameter of 9 mm., and is graduated into tenths of cubic centimeters above the mark (F).

Benzine (62° Beaumé naphtha) or kerosene free from water shall be used in making the determination. The flask is filled with either of these liquids to the lower mark (E) and 64 grm. of cement, cooled to the temperature of the liquid, is slowly introduced through the funnel (B), (the stem of which should be long enough to extend into the flask to the top of the bulb (C),) taking care that the cement does not adhere to the sides of the flask, and that the funnel does not touch the liquid. After all the cement is introduced, the level of the liquid will rise to some division of the graduated neck; this reading, plus 20 c.c., is the volume displaced by 64 grm. of the cement. The specific gravity is obtained from the formula,

$$\text{Specific gravity} = \frac{\text{Weight of cement, in grammes,}}{\text{Displaced volume, in cubic centimeters.}}$$

The flask, during the operation, is kept immersed in water in a jar (A) in order to avoid variations in the temperature of the liquid in the flask, which shall not exceed 1/2° C. The results of repeated tests shall agree within 0.01. The determination of specific gravity shall be made on the cement as received; if it should fall below 3.10,

a second determination shall be made after igniting the sample in a covered dish, preferably of platinum, at a low red heat not exceeding 900° C. The sample shall be heated for 5 minutes with a Bunsen burner (starting with a low flame and gradually increasing to its full height) and then heated for 15 minutes with a blast lamp; the ignition should preferably be made in a muffle.

4. Fineness

The fineness shall be determined by weighing the residue retained on No. 100 and No. 200 sieves. The sieves, 8 in. in diameter, shall be of brass wire cloth conforming to the following requirements:

No. of sieve	Diameter of wire, inches	Meshes, per linear inch	
		Warp	Woof
100	0.0042 to 0.0048	95 to 101	93 to 103
200	0.0021 to 0.0023	192 to 203	190 to 205

The meshes in any smaller space, down to 0.25 in., shall be proportional in number.

Fifty grams of cement, dried at a temperature of 100° C. (212° F.) shall be placed on the No. 200 sieve, which, with pan and cover attached, is held in one hand in a slightly inclined position, and moved forward and backward about 200 times per minute, at the same time striking the side gently, on the up stroke, against the palm of the other hand. The operation is continued until not more than 0.05 grm. will pass through in 1 minute. The residue is weighed, then placed on the No. 100 sieve, and the operation repeated. The work may be expedited by placing in the sieve a few large steel shot, which should be removed before the final 1 minute of sieving. The sieves should be thoroughly dry and clean.

5. Normal Consistency

The amount of water, expressed in percentage by weight of the dry cement, required to produce a paste[1] of the plasticity desired, termed "normal consistency," shall be determined with the Vicat apparatus:

This consists of a frame (*A*), Fig. 2, page 310, Year Book 1912, Amer. Soc. for Testing Materials, bearing a movable rod (*B*), weighing 300 grm., one end (*C*) being 1 cm. in diameter for a distance of 6 cm., the other having a removable needle (*D*), 1 mm. in diameter, 6 cm. long. The rod is reversible, and can be held in any desired position by a screw (*E*), and has midway between the ends a mark (*F*) which moves under a scale (graduated to millimeters) attached to the frame (*A*). The paste is held in a conical, hard-rubber ring (*G*), 7 cm. in diameter at the base, 4 cm. high, resting on a glass plate (*H*) about 10 cm. square.

In making the determination of normal consistency, the same quantity of cement as will be used subsequently for each batch in making the test pieces, but not less than 500 grm., together with a measured amount of water, is kneaded into a paste, as described in Section 9, and quickly formed into a ball with the hands, completing the operation by tossing it six times from one hand to the other, maintained about 6 in. apart; the ball resting in the palm of one hand is pressed into the larger end of the rubber ring held in the other hand, completely filling the ring with paste; the excess at the larger end is then removed by a single movement of the palm of the hand; the ring is then placed on its larger end on a glass plate and the excess paste at the smaller end is sliced off

[1] The term "paste" is used in these specifications to designate a mixture of cement and water, and the word "mortar" to designate a mixture of cement, sand and water.

at the top of the ring by a single oblique stroke of a trowel held at a slight angle with the top of the ring. During those operations care must be taken not to compress the paste. The paste confined in the ring, resting on the plate, is placed under the rod, the larger end of which is carefully brought in contact with the surface of the paste; the scale is then read, and the rod quickly released.

The paste is of normal consistency when the cylinder settles to a point 10 mm. below the original surface in 1/2 minute after being released. The apparatus must be free from all vibrations during the test.

Trial pastes are made with varying percentages of water until the normal consistency is attained.

Having determined the percentage of water required to produce a paste of normal consistency, the percentage required for a mortar containing, by weight, one part of cement to three parts of standard Ottawa sand, shall be obtained from the following table, the amount being a percentage of the combined weight of the cement and sand.

PERCENTAGE OF WATER FOR STANDARD MORTARS

Neat	One cement, three standard Ottawa sand	Neat	One cement, three standard Ottawa sand	Neat	One cement, three standard Ottawa sand
15	8.0	23	9.3	31	10.7
16	8.2	24	9.5	32	10.8
17	8.3	25	9.7	33	11.0
18	8.5	26	9.8	34	11.2
19	8.7	27	10.0	35	11.3
20	8.8	28	10.2	36	11.5
21	9.0	29	10.3	37	11.7
22	9.2	30	10.5	38	11.8

6. Time of Setting

The time of setting shall be determined with the Vicat apparatus in the following manner:

A paste of normal consistency is molded in the hard-rubber ring, as described in Section 5, and placed under the rod (*B*), the smaller end of which is then carefully brought in contact with the surface of the paste, and the rod quickly released.

The cement is considered to have acquired its initial set when the needle ceases to pass a point 5 mm. above the glass plate; and the final set, when the needle does not sink visibly into the paste.

The test pieces must be kept in moist air during the test.

The following methods are not standard but are here inserted by the authors as methods frequently used to determine normal consistency and time of set.

THE BALL METHOD FOR NORMAL CONSISTENCY.—The consistency obtained should be such that if a ball of paste about 2 in. in diameter be dropped from a height of 2 ft. upon a hard surface, it will not crack nor flatten to more than half of its original diameter. This method gives a trifle drier cement paste than the Vicat test.

THE GILMORE TEST FOR TIME OF SETTING.—The Gilmore needles consist of needles supporting weights, one has a diameter at bottom of needle of 1/12 in. and a weight of 1/4 lb., and the other a diameter of 1/24 in., and a weight of 1 lb. The cement paste is molded into a standard pat on glass and stored in moist air, and the time observed when it will sustain these needles without indentation. The 1/4 lb. gives the initial and the 1-lb. needle the final set of the cement. Care should be taken to see that the needles are clean and applied slowly and perpendicularly to the cement surface. Time of set as obtained with the Vicat tests ranges from one-half to three-quarters of the time as determined with the Gilmore tests.

7. Standard Sand

The sand shall be natural sand from Ottawa, Ill., screened to pass a No. 20 sieve, and retained on a No. 30 sieve.

The sieves shall be at least 8 in. in diameter, and the wire cloth shall be of brass wire and shall conform to the following requirements:

No. of sieve	Diameter of wire, inches	Meshes, per linear inch	
		Warp	Woof
20	0.016 to 0.017	19.5 to 20.5	19 to 21
30	0.011 to 0.012	29.5 to 30.5	28.5 to 31.5

Sand which has passed the No. 20 sieve is standard when not more than 5 grm. passes the No. 30 sieve in 1 minute of continuous sifting of a 500-grm. sample.[1]

8. Form of Test Pieces

For tensile tests, the form of test pieces shown in Fig. 3, page 313, Year Book 1912, Amer. Soc. for Testing Materials, shall be used.

For compressive tests, 2-in. cubes shall be used.

9. Mixing and Molding

The material shall be weighed, placed on a non-absorbent surface, thoroughly mixed dry if sand be used, and a crater formed in the center, into which the proper percentage of clean water shall be poured; the material on the outer edge shall be turned into the center by the aid of a trowel. As soon as the water has been absorbed, the operation of mixing shall be completed by vigorously kneading with the hnads for 1 minute.

[1] This sand may now (1912) be obtained from the Ottawa Silica Co., at a cost of two cents per pound, f. o. b. cars, Ottawa, Ill.

Immediately after mixing, the paste or mortar shall be placed in the mold (Figs. 4 and 5, page 314, Year Book for 1912, Amer. Soc. for Testing Materials) with the hands, pressed in firmly with the fingers, and smoothed off with a trowel without ramming. The material shall be heaped above the mold, and, in smoothing off, the trowel shall be drawn over the mold in such a manner as to exert a moderate pressure on the material; the mold shall then be turned over and the operation of heaping and smoothing off repeated.

The temperature of the room and of the mixing water shall be maintained as nearly as practicable at 21° C. (70° F.).

10. Storage of the Test Pieces

During the first 24 hours after molding, the test pieces shall be stored in a moist closet. This consists of a box of soapstone or slate, or of wood lined with metal, the interior surface being covered with felt or broad wicking kept wet, the bottom of the box being kept covered with water. The interior of the box is provided with glass shelves on which to place the test pieces, the shelves being so arranged that they may be withdrawn readily.

Test pieces from any sample which vary more than 3 per cent. in weight from the average, after removal from the moist closet, shall not be considered in determining strength.

After 24 hours in the moist closet, the pieces to be tested after longer periods shall be immersed in water in storage tanks or pans made of non-corrodible material.

The air and water in the moist closet and the water in the storage tanks shall be maintained, as nearly as practicable, at 21° C. (70° F.).

11. Tests of Tensile Strength

The tests may be made with any standard machine.

The clip is shown in Fig. 6, page 315, Year Book 1912, Amer. Soc. for Testing Materials. It must be made accurately, the pins and rollers turned, and the rollers bored slightly larger than the pins so as to turn easily. There should be a slight clearance at each end of the roller, and the pins should be kept properly lubricated and free from grit. The clips shall be used without cushioning at the points of contact.

The test pieces shall be broken as soon as they are removed from the water. The load shall be applied at the rate of 600 lb. per minute.

Test pieces which do not break within 1/4 in. of the center, or are otherwise manifestly faulty, shall be excluded in determining average results.

12. Tests of Compressive Strength

The tests may be made with any machine provided with means for so applying the load that the line of pressure is along the axis of the test piece. A ball-bearing block for this purpose is shown in Fig. 7, page 317, Year Book 1912, Amer. Soc. for Testing Materials.

The test pieces as soon as they are removed from the water shall be placed in the testing machine, with a piece of heavy blotting paper on each of the crushing faces, which should be those that were in contact with the mold.

13. Constancy of Volume

Tests for constancy of volume comprise "normal tests" which are made in air or water, maintained as nearly as

practicable, at 21° C. (70° F.), and the "accelerated test," which is made in steam. These tests shall be made in the following manner:

Pats about 3 in. in diameter, 1/2 in. thick at the center, and tapering to a thin edge, shall be made on clean glass plates (about 4 in. square) from cement paste of normal consistency, and stored in a moist closet for 24 hours.

Normal Tests.—After 24 hours in the moist closet, a pat is immersed in water and observed at intervals. A similar pat, after 24 hours in the moist closet, is exposed to the air for 28 days or more and observed at intervals. The air and water are maintained, as nearly as practicable, at 21° C. (70° F.).

Accelerated Tests.—After 24 hours in the moist closet, a pat is placed in an atmosphere of steam, upon a wire screen 1 in. above boiling water, for 5 hours the apparatus being such that the steam will escape freely and atmospheric pressure be maintained. The apparatus is shown in Fig. 8, page 318, Year Book 1912, Amer. Soc. for Testing Materials.

The cement passes these tests when the pats remain firm and hard, with no signs of cracking, distortion, or disintegration.

Article 5

Study of Aggregates

Notes on the Sampling of Aggregates used in Concrete Construction.—The value of tests of the constituent materials entering into a concrete construction depend almost entirely upon whether the samples obtained are thoroughly representative of the aggregates used.

When it is positively certain that the material sampled

is the material shipped and used in the construction then the samples may be taken at the pit. When there is uncertainty as to this point, samples for test should be taken from shipments as they arrive where they are to be used.

Sampling at a pit which has exposed vertical faces may be done by scooping out a small uniform vertical channel from bottom to top of faces. If the material excavated from this channel is more than desired it may be reduced by the method of quartering. Samples taken in this way from the various faces of a pit should be kept separate with the proper identification as to location, inasmuch as it may happen that some parts of the same bank may yield an undesirable material.

Sampling the aggregate after it has arrived on the job may be done by collecting and mixing a small quantity from many different parts of the pile, or bin. These small quantities should be obtained by digging into the pile not by collecting what rolls down the outside as that is likely to be composed of only the coarser particles. The test samples themselves should always be acquired from the larger samples by the method of quartering.

QUARTERING.—To quarter a sample of aggregate it is spread out on a clean flat surface in the form of a circular disc of uniform thickness. Care should be taken that particles of different size are distributed through the mass. The material is then divided into four quarters and two opposite quarters removed completely. The remaining quarters are then mixed together and the operation repeated. This is done until the quantity remaining is the size required for the experiment.

SHIPPING AND STORING OF SAMPLES.—The samples should be shipped and stored in such a way as to retain as much as possible of the natural moisture of the material.

Experiment E-2

Determination of the Amount and Character of the Silt or Other Fine Material in an Aggregate

References.—

Baker's Masonry Construction, 1910, Chap. V., pp. 86–88.

Taylor & Thompson, Concrete, Plain and Reinforced, 1907, Chap. IX, pp. 154.

Recommended Specifications of National Assoc. of Cement Users, 1912.

Materials.—The sand or coarser aggregate should be tested in as nearly its natural condition as possible.

Method of Tests. Suspension Method.—A graduate (either 500 c.c. or 1000 c.c.) should be filled half full with the material to be tested. The material should be well compacted into the graduate, small quantities being tamped in at a time. The graduate should now be filled with clear water and the contents throughly stirred and shaken until the fine material is entirely in suspension. The volume of the solid matter is then read before and after a complete settlement of suspended material. The volume of the fine material should be expressed as a percentage of the original volume of material.

Wet Screening Method.—The per cent. moisture having been previously obtained 500 grm. of the material in its natural state should be then thoroughly washed under running water and dried in the oven. The loss in weight in the sample should be expressed as a per cent. of the dry weight of original sample.

Character of Silt and Amount of Organic Matter.—By a process of elutriation or decanting the silt may be washed from the material and thus be available for chemical or other observations.

Tamp a known weight of the sand in its natural condition into a graduate noting the resulting volume. Fill the graduate with clear water (distilled water will be necessary if chemical examination is desired) and thoroughly stir and shake the contents. The dirty water should be then poured off into another vessel and the operation repeated until the resulting wash water is clear.

The decanting water is then filtered through a previously weighed filter paper and the residue and paper dried in the oven at approximately 212° F. The net weight of the dried residue expressed as a per cent. of the original dry weight of sample gives the proportion of silt in the material.

The residue and filter paper may be ignited in a weighed crucible at a red heat. The loss in weight expressed as a per cent. of original dry weight of sample gives the amount of organic matter present.

Experiment E-3

The Specific Gravity of Various Materials Used as an Aggregate in Concrete

Object.—The object of this test is to determine the specific gravity of the various materials used as an aggregate in concrete.

References.—

Taylor & Thompson, pages 160 to 168. Baker's Masonry Construction.

Materials.—The following materials will be used: sand or gravel, stone. A porous material should first be moistened to fill the pores and the surfaces of the particles be dried by means of blotting paper. A correction for the weight of absorbed moisture can be made by drying the material in an oven.

METHOD.—Weigh graduate and fill half full of water and weigh again, being careful to see that weight of water and volume check. Add an equal volume of the dry aggregate after weighing, and note the exact rise of the water level. Let W = weight of material, and G weight of water displaced. Then specific gravity of the material $= S = \frac{W}{G}$.

CONCLUSION.—Compare results with those in Taylor & Thompson's treatise.

Report should be in standard form.

Experiment E-4.

DETERMINATION OF VOIDS IN AGGREGATES

The voids in an aggregate are the interstices between the particles.

The total volume of hollow spaces constitute the absolute voids. The total volume of hollow spaces minus volume occupied by moisture constitute the air filled voids.

MATERIAL.—Any aggregate, usually sand, gravel or broken stone, thoroughly dried.

SPECIAL APPARATUS.—For coarse materials: Use a vessel which is water tight and capacity is at least 1/2 cu. ft. Volume of water may be determined by weighing.

For finer materials: Use a 1000 c.c. graduate or 500 c.c. graduate if very fine materials are being measured. Volume of water may be either measured or weighed.

PROCEDURE.—(a) DETERMINATION OF VOIDS BY DIRECT MEASUREMENTS.—In this method determine a known volume (varies with size, being larger for coarser sizes) of aggregate in the state in which the percentage of voids is required, *i.e.*, loose, shaken or packed.

The method of determining the volume of hollow spaces varies with the character and size of particles.

COARSE AGGREGATE (contains no particles under 1/4 in.) Pour water directly into the aggregate till the voids are filled, the volume of the water poured in equals the volume of the voids.

AGGREGATE CONTAINING PARTICLES UNDER $\frac{1}{4}$-IN. DIAMETER.—Either introduce the water slowly from the bottom by means of a special apparatus, thus keeping out entrained air or pour a known volume of aggregate slowly into a known volume of water, noting the rise in level of water. The last two methods are not exact inasmuch as they allow some entrained air, but they will be found sufficiently accurate for practical purposes.

(b) DETERMINATION OF VOIDS BY SPECIFIC GRAVITY METHOD.—In this method the specific gravity must be known or be determined as in Experiment E-2.

Knowing the specific gravity of the aggregate, the weight of a cubic foot of the solid material may be determined.

Then determine the weight of a known volume of the aggregate in the state in which the percentage of voids is required, that is, loose, shaken or packed. From these weights the percentage of voids may be figured.

Experiment E-5

EFFECT OF MOISTURE IN AGGREGATES ON PER CENT. OF VOIDS

OBJECT.—The object of this test is to determine the effect of moisture on concrete aggregates with respect to the per cent. of voids.

READING.—Taylor and Thompson, pages 176–179.

Material.—The following materials will be used: Fine sand, coarse sand, gravel.

Apparatus.—1000 c.c. graduate, 100 c.c. graduate, metric scale, pan.

Method.—Weigh a large 1000 c.c. graduate flask and fill half full of the dry material to be tested. Record the weight and the level of the material. Pour dry material into a pan and add 2 per cent. (by weight) of water to dry sand, and agitate thoroughly. Return dampened material to flask. Shake well and uniformly (one batch no more than the others) and record the new level of the sand. Add water in like increments of 2 per cent. until the material is thoroughly saturated, recording the new level after each addition of water. Note how sand feels to the touch at different per cents. of moisture.

Curves.—Show by curves the relation between per cent. moisture and weight per cubic foot. Show also the relation between per cent. voids and per cent. moisture.

Calculations.—Assume specific gravity equal to 2.6, calculate per cent. absolute voids, per cent. air voids, weight per cubic foot for each per cent. of moisture.

Report should be in regular form.

Experiment E-6

Effect of the Size of Particles on the Density of the Materials

Object.—The object of this test is to determine the effect of the size of particles on the density of a material.

Reading.—Taylor & Thompson, pages 168–174.

Material.—Coarse sand, gravel or broken stone.

Method.—By screening, separate a dry material (sand gravel or broken stone) into particles of four uniform sizes, as: 2–4, 8–20, 30–40, and 50–100. Determine the per

cent. of voids in each of these samples. Select a sample of the largest size, 2–4, and add enough of second size, 8–20, to fill the voids and determine the voids in the mixture. Add in order of sizes determining the per cent. of voids after each smaller size has been added.

Note.—In finding the voids, measure the volume, V, of dry material to be tested, then pour it into a flask containing a known quantity of water. The rise of water level will show the absolute volume, V', of material. Per cent. of voids then equals $\frac{V-V'}{V}\times 100$.

Conclusion.—Report the effect of size of particles on the density. Is it worth while to use so many grades? Suggest the proper sizes for economy in forming an aggregate. Give reasons for your suggestion.

Compare results with Experiment F-6. Draw conclusions. See general form of report.

Experiment E-7

Relative Density of Sharp and Round Particles of the Same Size

Object.—The object of this test is to determine the relative density of sharp and round particles of the same size.

Reading.—Taylor & Thompson, Concrete, Plain, and Reinforced, pages 174–176.

Materials.—Chilled lead shot, sharp sand and Ottawa sand.

Method.—Select a sample of shot of uniform size of particles and determine the size of particles by screening on No. 20 and No. 30. Select samples of (a) sharp and (b) rounded sand (Ottawa sand) of the same screen size

as the shot. Determine the per cent. of voids in these three samples by method in which a given volume of aggregate is poured into a given volume of water.

What is the theoretical per cent. of voids in the vessel of equal spheres?

Conclusions.—Draw conclusions as to the efficiency of sharp and rounded sand.

Experiment E-8

Sieve Analysis of Aggregates

The experiment gives graphically the gradations of sizes in an aggregate and by comparisons with a theoretical ideal aggregate the improvement of the aggregate may be known.

Reference.—

Trans. American Society Civil Eng'rs, Vol. LIX, p. 90—Baker's Masonry Construction.

Material.—Gravel and sand or broken stone with screenings, or stone and sand, well dried.

Apparatus.—Sieves as follows: 2 in., 1 1/2 in., 1 in., 3/4 in., 1/2 in., and Nos. 3, 4, 8, 10, 16, 20, 30, 40, 50, 80, 100 and 200.

Procedure.—A representative sample of the aggregate should be chosen weighing 1000 or 2000 grm. The coarser the aggregate, the larger should be the size of the original sample. The sample should be separated into its sizes by sieving, beginning with the largest sieves. The amount remaining on each sieve after five minutes, shaking should be weighed, also the amount passing the finest sieve. If the sum of these is not equal to the original weight, distribute the error proportionately.

Note the actual size of the largest particle in the sample.

Computations.—Plot a diagram with per cents. pass-

ing the sieve as ordinates and size of mesh of the different sieves as abscissæ.

The ideal gradation of sizes of aggregate plus cement is shown by a curve drawn as follows: The curve starts upon and is tangent to the zero axis of percentages at 7 per cent., and runs as an ellipse to a point on a vertical ordinate whose value represents a size about one-tenth of the diameter of the largest particle, and thence by a tangent straight line to the 100 per cent. point on the ordinate of largest size of particle in the sample.

The equation for the ellipse is:

$$(y-7)^2=\frac{b^2}{a^2}(2ax-x^2)$$

	b	a
For stone and screenings	$29.4+2.2D$	$0.055+0.14D$
For gravel and sand	$26.4+1.3D$	$0.04+0.16D$
For stone and sand	$28.5+1.3D$	$0.04+0.16D$

NOTE.—The above constants vary with the different materials which may be used in concrete constructions, and to be strictly accurate must be determined for each material. However, these values may be considered average and used as such may be considered accurate enough for practical purposes.

DISCUSSION OF RESULTS.—In what sizes of particles is the aggregate deficient? How many this be remedied in a practical way?

If the aggregate should be screened into two or more parts and these recombined in new proportions, indicate on what sieves to screen, and the new proportions of each size to use.

Give the proportions for an assumed concrete.

SIZES OF COMMERCIAL SIEVES

(Approximate)

Commercial No. of sieve	Diam. of hole in inches	Commercial No. of sieve	Diam. of hole in inches
3	0.30	50	0.011
4	0.22	60	0.009
8	0.12	74	0.0078
10	0.073	80	0.007
15	0.047	100	0.0045
16	0.042	140	0.003625
18	0.037	150	0.00325
20	0.034	170	0.0031
30	0.022	190	0.0028
35	0.017	200	0.00275
40	0.015	....	....

Article 6

Proportioning Mortars and Concretes

Experiment E-9

PURPOSE.—The purpose of this experiment is to determine the increase in volume in an aggregate caused by the addition of a given volume of a finer material.

References.—

Tayler & Thompson, Concrete, Plain and Reinforced, 1907, Chapter VI, p. 10.

Baker's Masonry Construction, 1910, Paragraphs 297 to 300.

SPECIAL APPARATUS.—

For fine materials.

A 500 c.c. graduate.

Scales for weighing with gram weights.

A small wood tamper.

For coarse materials.

An iron vessel (an 8-in. pipe 1 ft. long with one end closed water tight is a convenient apparatus).

A steel scale or other means of measuring contents of vessel.

Method of Test.—The coarser material should be in the condition in which it is being used on the work. A given volume of this should be determined by tamping into the measuring vessel in small quantities. It should then be emptied out upon a non-absorbent surface or pan and to it the desired volume of finer material be added and the whole thoroughly mixed. The mixed materials should then be tamped back into the measuring vessel and the increase in volume determined.

Report.—The report should be in the standard form.

What is the significance of the results of these tests in the proportioning of concrete materials?

Experiment E-10

Proportioning Concrete by Method of Void Determinations

The cases which may arise are as follows:

Case 1.—Single aggregates containing coarse and fine particles such as "Run of Bank" gravel or "Crusher Run" stone.

Case 2.—Two aggregates in which one is screened stone or gravel and the second is sand, screenings or other fine material.

Procedure. Case 1.—Measure the voids in the dry loose aggregate by the method in Experiment E-4 for similar material. In practical use, correction should be made for moisture in the aggregate as it is used in the work.

Case 2.—Measure the voids in the coarse material and fine material as in Experiment E-4. The sample should be dry and loose, inasmuch as the loose volume

more nearly equals the volume of the resulting concrete. Theoretically the mortar, made up of cement paste and the sand should just fill the voids in the coarse material. And the cement paste should just fill the voids in the fine material.

It has been found that addition of cement paste to sand increases the volume of the sand from 2 to 5 per cent. and the addition of mortar to coarse material increases the volume of the coarse material from 2 to 10 per cent., so that it is necessary to use a small excess of cement paste, and an excess of mortar in order to be certain that the resulting mixture has no voids. However, if the coarse aggregate is coarse crushed stone of large size, say 1 1/2-in. or 2-in. diameter, the mortar may equal the voids in the stone since the addition will not increase the volume of the stone to any extent. The exact excess percentages to be used in any given case may be found as in Experiment E-9. It may be assumed without appreciable error that 100 lb. of cement will make 1.0 cu. ft. of neat cement paste. To the quantity of cement thus determined 10 per cent. of its weight may be added to provide for waste and imperfect mixing. Give proportions for best concrete using aggregates tested.

Illustration of Method of Proportioning Concrete by Void Determinations

The material to be used:

Crushed limestone 1/4 in. to 1 1/2 in. in size. Voids 45 per cent.

Bank sand 00 to 1/4 in. size. Voids 30 per cent.

Portland cement (100 lb. will make 1 cu. ft. cement paste).

Theoretically the proportions would be stone 100 per cent., sand 45 per cent. and cement 13.5 per cent.

or 1:3.3:7.4 as usually given. Assume that the addition of cement paste to sand increases its volume 5 per cent. and that the addition of cement-sand mortar to crushed limestone of this range of size increases its volume 10 per cent. (These per cents. may be determined as in Experiment E-9.)

Computations.—

To make 1 cu. ft. of Concrete.

(1) Volume of stone needed $= 1 \div 1.10 = 0.91$ cu. ft.

(2) Volume of voids in stone $= 0.91 \times 0.45 = 0.409$ cu. ft.

(3) Volume of mortar required $= 0.409 + 0.09 = 0.499$ cu. ft.

(4) Volume of sand required $= 0.499 \div 1.05 = 0.475$ cu. ft.

(5) Volume of voids in sand $= 0.475 \times 0.30 = 0.142$ cu. ft.

(6) Volume of cement paste $= 0.142 + 0.024 = 0.166$ cu. ft.

The weight of cement required $= 100 \times 0.166 = 16.6$ lb. Assuming the weight of a cubic foot of dry packed cement to be 100 lb. the proportions by volume are 0.166: 0.475: 0.91 or 1:2.86 : 5.48. If a 10 per cent. increase in the amount of cement is used to provide for waste and imperfect mixing then the proportions by volume become 1:2.6 : 4.98.

Experiment E-11

Proportioning Concrete by Method of Sieve Analysis

The cases which may arise are in general, the following:

Case 1.—A single aggregate is separated into two or more sizes and re-combined.

Case 2.—Two or more aggregates are to be combined.

(a) When their analysis curves meet, but do not overlap.

(b) When their analysis curves wholly or partly overlap.

Procedure. Case 1.—Perform the operation of mechanical sieving upon the aggregate and draw sieve analysis curve together with curve for ideal mixture as directed in Experiment E-8.

Study the curves to decide how many and what sizes to screen the aggregate into so that the re-combination of parts may be as near as practicable to the ideal curve.

Note.—It is not practicable in most cases, on account of extra expense, to screen into more than three sizes of aggregate.

Now treat each size of aggregate as a complete sample and re-draw its curve to the original scale. This is most easily done by manipulation of values by slide rule. See Fig. 28.

There are now represented on diagram sheet, two or more aggregates, as the case may be, whose curves do not overlap in sizes, and drawn to the same scale. These should be combined according to the demands of the ideal curve for the mixture.

Give the percentages of each to use and draw the combined curve. For methods, see Baker's Masonry Construction, or Concrete, Plain and Reinforced, by Taylor and Thompson.

Give the proportions by weight for an assumed concrete, *i.e.*, 1 to x concrete.

Case 2.—(a) Perform the operations and draw the curves as in Experiment E-8. The curves of the different aggregates should be drawn to the same scale on the same sheet. The Ideal curve for the mixture should be drawn from the 100 per cent. point on the ordinate of the largest

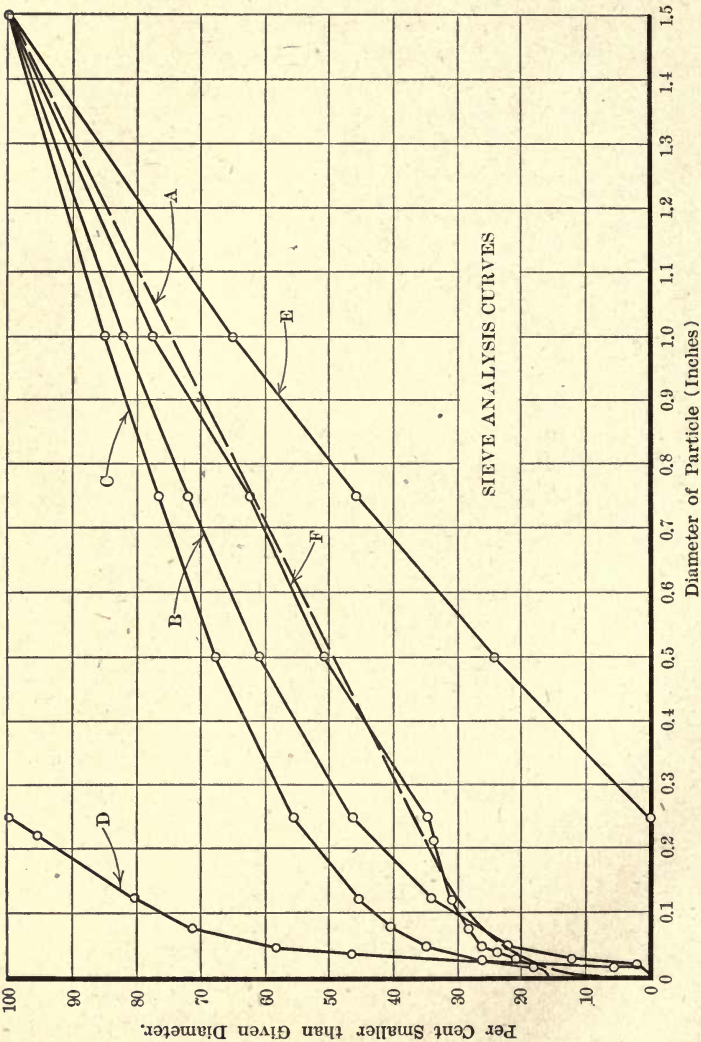

SIEVE ANALYSIS CURVES
A
B
C
D
E
F
Per Cent Smaller than Given Diameter.
0
10
20
30
40
50
60
70
80
90
100
Diameter of Particle (Inches)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5

FIG. 28.

size of particle and the coarsest aggregate. The method of combining the different aggregates is given in Case 1.

(b) Perform the operations and draw the curves as directed in E-8 and (a) above.

For method of combination and drawing combined curves see Baker's Masonry Construction and Concrete, Plain and Reinforced, by Taylor and Thompson.

Illustration of Method of Proportioning Concrete by Sieve Analysis

In Fig. 28 the following curves are shown:

Curve *A* represents the ideal curve of maximum density for a mixture of cement, sand and gravel where the size of the largest particle is 1 1/2 in.

Curve *B* represents an ordinary "Run of Bank" sample of gravel in which the size of the largest particle is 1 1/2 in.

Curve *C* represents a 1 to 5 (by weight) mixture of cement and gravel as shown in Curve *B*.

Curve *D* represents the sand finer than 1/4 in. in the Run of Bank gravel, plotted to the same scale.

Curve *E* represents the gravel coarser than 1/4 in. in the "Run of Bank" as represented by Curve *B* and plotted to the same scale.

Curve *F* represents a 1 to 5 (by weight) mixture of cement and sand as represented by Curve *D* and gravel as represented by Curve *E*.

Any mixture of cement and the run of bank gravel as represented by Curve *B*, will be far from the ideal maximum density mixture as represented by Curve *A*. If, however, the run of bank is screened into two parts, *i.e.*, sand finer than 1/4 in. represented by Curve *D* and gravel coarser than 1/4 in. represented by Curve *E*, the mixture

of cement plus aggregate may be made to conform closely to the ideal. The ratio of cement to aggregate must be assumed in any case and depends upon the quality of concrete desired. In Fig. 28 the ratio of cement to aggregate was assumed to be 1 to 5 by weight. In any mixture of 1 to 5 concrete the cement is 1 divided by 6 equals 16.6 per cent. by weight of the whole. The ideal calls for 37 per cent. finer (equals sand plus cement) than a 1/4 in. size and 63 per cent. coarser than 1/4 in. size. To give a still closer approach to the ideal 35 per cent. finer than 1/4 in. and 65 per cent. coarser than 1/4 in. were taken.

The mixture, to conform closely to the ideal, will have then 35 per cent. by weight finer than 1/4 in. and this will be made up of sand plus cement, and since the cement in a 1 to 5 mixture is 16.6 per cent. of the whole, then $35-16.6=18.4$ per cent. is the per cent. by weight of sand smaller than 1/4 in. in the mixture. The proportions of cement, sand, and gravel for the total mixture of 1 to 5 concrete are then 16.6 per cent. cement, 18.4 per cent. sand as represented by Curve *D* and 65 per cent. gravel as represented by Curve E. This corresponds to the proportion by weight of 1 :1.1 :3.9. And the curve of the mixture (Curve *F*) is seen to conform much closer to the ideal maximum density curve than a 1 to 5 mixture (Curve *C*) of cement and the original "Bank Run" gravel.

Experiment E-12

The Yield or Volumetric Test of Sands

The object of this test is to determine which of two or more sands will give the denser, and therefore the stronger, mortar in any given proportion.

References.

Natl. Assoc. of Cement Users, Vol. II, p. 24.

Taylor & Thompson, Concrete, Plain, and Reinforced, 1905, p. 136.

Materials.—Two or more sands or other fine aggregate to be used in concrete construction. The test should be made on a dry sample of the sand, but if sand as used in the work contains moisture, correction of the proportions found, must be made for the amount of moisture present.

Method.—The proportions of cement and sand should be such by dry weight as to give the desired proportion by moist volume, that is the proportions actually to be used on the work. This will of course have to be ascertained in any given case.

A batch of 600 grm. of the dry materials should be well mixed for about one minute in a clean shallow pan. An amount of clear water should be then added to give a plastic mortar and the whole well mixed for 4 minutes. The mortar should then be lightly tamped into a 500 c.c. graduate with a light wood tamper. About 20 c.c. of the mixture should be introduced at a time. After allowing the mortar to settle for some time the surplus water should be poured off and the volume of mortar read.

The other sands should be treated in the same way using the same proportions by dry weight and enough water to give the same consistency.

The sand which gives the least volume of mortar, *i.e.*, which has the least volume of voids is the best sand provided there is no other ingredient present to affect the strength and setting.

If desired, strength test specimens may be molded from the resulting mortar in each case.

Report.—The report should be in standard form.

Experiment E-13

Proportioning Concrete by Volumetric Synthesis

Object.—The object of this test is to determine, by trial mixtures, the proportions of the aggregates for the densest concrete.

Reading.—Taylor & Thompson, Concrete, Plain and Reinforced, page 209. Baker's Masonry Construction, page 146.

Material.—Portland cement and a uniform sand and stone, or gravel.

Special Apparatus.—One tamping rod, 1 ft. steel scale. A cylindrical vessel water-tight (an 8-in. or 10-in. pipe closed at one end will do).

Method.—Mix a batch of concrete, as directed by the instructor, using arbitrary proportions for a 1 to 6 concrete, and record accurately the weights of materials used. Tamp the batch into the mold and record volume.

Note.—The handling of the mixture, consistency and method of putting into molds depends upon the use of the concrete. These must be kept constant in this experiment. Empty and clean the vessel before concrete has had time to set.

Mix another batch, using the same weight of cement but varying the quantities of sand and stone, keeping the total quantity constant. The weight of water used will differ and should be such as to give a constant consistency. Tamp this batch in the mold as before, and record volume.

Repeat the process until the proportions giving the densest concrete are found. Try first 1-1-5, then 1-2-4, 1-$2\frac{1}{2}$-$3\frac{1}{2}$, 1-3-3, 1-4-2.

Make two cylinders from each of these proportions and test at the end of seven days. Compare the strength

with that of the cylinders from the first or arbitrary proportions at seven days.

Be careful to do all the work uniformly.

Article 7

Tests of Concrete and Other Brittle Materials

Experiment F-1

The Value of a Sand or Other Fine Aggregate as Shown by Strength Tests

Purpose.—This test is to determine the strength of a natural sand mortar as compared with strength of a standard Ottawa Sand Mortar.

References.—

Baker's Masonry Construction, Chap. V, 1910.

Recommended Specifications of Natl. Assoc. of Cement Users, 1912.

Material.—Any sand or fine material used as a concrete aggregate. This material should all pass a $\frac{1}{4}$-in. sieve. The original moisture in the sand should be present if possible, in which case a correction for weights must be determined by drying a separate sample.

The cement used should be a mixture in equal parts of several standard Portland cements.

Method.—In determining the tensile strength, nine briquettes of standard Ottawa sand and cement in the proportion of 1 part cement by weight to 3 parts Ottawa sand, should be made in the regular way. See Experiment D-6.

The same number of briquettes should be made using the sand under test. The correction for weight due to moisture should be made. This damp sand should first be thoroughly mixed with the required amount of cement

until the whole is a uniform color. Water should then be added until the consistency is the same as that of the standard sand mortar. Care should be used in this determination.

Test 3 briquettes at 72 hours, 3 at 7 days and 3 at 28 days age. Report the strength of each briquette and the average of the three. The compressive strength may be obtained by repeating the operation and methods except that the 2-in. cube is the test piece used.

REPORT.—The report should be in standard form. The ratio of the strength of the test sand to that of the standard sand mortar should be noted.

If the sand proves to be defective what tests should be made to ascertain the cause?

Experiment F-2

(See also Exp. F-3)

COMPRESSIVE STRENGTH OF CONCRETE.

The object of this experiment will be to determine the compressive strength of concrete.

References.—

Baker's Masonry Construction, pages 194 to 217.

MATERIAL.—Use broken stone (or gravel), sand and Portland cement.

APPARATUS.—Six cylindrical molds.

METHOD OF MAKING TEST SPECIMENS.—Make two cylinders 8 in.$\times$16 in., using one of the following proportions:

1 part cement	2 parts sand	4 parts broken stone.
1 part cement	$2\frac{1}{2}$ parts sand	5 parts broken stone.
1 part cement	3 parts sand	6 parts broken stone.
1 part cement	4 parts sand	8 parts broken stone.

In computing amounts necessary use the following rule:

$$P = \frac{1.55}{c+s+g}$$

P = the part of a cu. ft. of cement necessary to make a cu. ft. of concrete.
c = number of parts of cement.
s = number of parts of sand.
g = number of parts of stone or gravel.
The amount of stone required $= P \times g$ (cu. ft.)
The amount of sand required $= P \times s$ (cu. ft.)

Scatter stone evenly in layer over the mixing board, add sand in layer on top and add cement on top of sand. Turn four times dry, then, using sprinkler, wet mixture as it is turned until water will just appear on surface when struck flatly with shovel. Tamp concrete in cylinders in layers of 4 in. Carefully smooth off the top and make cylinder stand vertical. Be sure top and bottom bases are both perpendicular to axis of cylinder. Test in 7 or 28 days. For method of test see F-3 and F-4.

Experiment F-3

Compression Test Brittle Materials

The purposes of this experiment are: To obtain knowledge of the proper methods of testing materials in compression; of the crushing strength of such materials; and of the characteristic forms of fracture.

Material.—Three 8 in.×16 in. concrete cylinders, or three bricks, or terra cotta, or any building material in proper form for compression test.

Preliminary.—(1) Before testing any specimen carefully measure its height and cross section.

(2) When brick, stone, concrete, or cement specimens are to be tested they should be carefully bedded either with blotting paper or with plaster of Paris. (See Fig. 6.) To bed a specimen with plaster of Paris, have the testing machine balanced, and the head down so far that it will clear the specimen only about one inch or two. Then mix up some plaster of Paris and water to a very thick, creamy consistency. Spread a thin layer of this on paper placed upon the spherical bearing block of the machine and cover it with a piece of tough sized paper, upon which the specimen should then be placed. The paper is to keep the water of the plaster out of the specimen. Upon another similar piece of paper a similar pad of the plaster should be spread covered with another piece of paper to form a pad, and the pad then placed upon the specimen. The head of the machine should then be run down rapidly until it presses upon the plaster sufficiently to cause it to flow, thus insuring a good bedding. With the trowels now fill up all the open spaces about the edges of the specimen near the faces of the machine. After letting the plaster set until hard, the specimen is ready to be compressed. Have the work inspected by the instructor before proceeding.

In the case of all materials see that the ends of the specimen admit of a good even bearing in the machine.

The Test.—Using the slowest speed available, now compress the specimen, meanwhile keeping the scale beam floating; and watch carefully the behavior of the specimen.

Computation.—Compute the stress in pounds per square inch at first crack, and at maximum load.

Results.—Load and crushing strength at first crack and at maximum load or failure. Sketch form of fracture.

Comparison of results with standard values.

See general form of report.

Experiment F-4

Compression of Brittle Materials with Deformation Measurement

Object.—In addition to determining the maximum strength in compression, as in other compression tests, it is intended in this experiment to find the strength at elastic limit, the modulus of elasticity, and the modulus of elastic resilience.

Material.—The material should be of a cylindrical form if possible. A gage length of at least 8 in. should be available.

Apparatus.—Compressometer reading to 1/10,000 in.

Operations in Testing.—Proceed as in other compression tests except that the load is applied in increments of ——pounds (about one-twentieth of the probable maximum load) and the total amount of compression at each increment is measured by a compressometer. (Use slowest speed of the machine.)

Computations.—Plot points with load in pounds for ordinates and compression in inches for abscissæ. Draw a straight line averaging the points preceding the elastic limit, if any; and, tangent to this straight line, draw a smooth curve averaging the remaining points. (Consult instructor before inking in these lines.) Mark the points of maximum load and elastic limit, which latter is the point of tangency of the straight line and the smooth curve. Then draw a line through the origin parallel to the straight line previously drawn through the plotted points. (Do not continue this line beyond elastic limit.) Mark the point of elastic limit, if any, on corrected line.

The modulus of elasticity is calculated from the

formula $E=\frac{Pl}{F\lambda}$ where P and λ are the load in pounds and compression in inches respectively, for any point on the corrected line; F is the square inches of cross-sectional area of the specimen, and l is the gage-length in inches.

The moduli of elastic resilience and of rupture-work are the work done on each cubic inch of material in deforming it up to the elastic limit and ultimate strength respectively. These moduli may be obtained from the curve of plotted points by multiplying the area under the curve up to the point considered by the scale value of each unit area of the coordinate paper or by computation from observed data.

Experiment F-5

Reinforced Concrete Beam Test

This experiment follows compressive strength test. The same proportions will prevail. The object of this test is to investigate the action of a reinforced concrete beam.

Material.—Same as in Experiment F-2 with the addition of steel for reinforcement.

Method of Making and Test.—Make concrete as in Experiment F-2 only a little wetter. Wet forms and cover bottoms of mold with about 1 in. of concrete, then place the rods in position. Ram and spade the concrete well about forms and rods. Level off the top and cover with damp cloth. Sprinkle every day for ten days.

The test will be under supervision of the instructor. Determine the load-deflection curve and stress in steel and concrete, if possible, by means of the Berry strain gage.

Report will cover, (1) Description of materials, kind,

brand, voids, strength of cement, etc. (2) Proportions. (3) Design of beam. (4) Per cent. of steel. (5) Stresses in concrete and steel at first crack and maximum by formula, and by test.

Experiment F-6

Strength of Concrete With Varying Gradation of Sizes of Aggregates

Purpose.—The purpose of this experiment is to test the value of the elliptic law which is sometimes used for determining the proportionate volume of different sizes of particles in an aggregate to produce the strongest resulting concrete.

References.

Taylor Thompson, Reinforced Concrete. Chap. XI, pages 194, 209, 210, 211, 212. Purdue Engineering Review, 1908, page 45.

Materials.—Graded aggregates between sieves 2-1 1/2, 1 1/2-1, 1-3/4, 3/4-1/2, Nos. 2-4, 4-8, 8-20, 20-30, 30-50, and 50-00.

Procedure.—This experiment should follow Exp. E-3, and the elliptic curve will be used for determining the amounts of aggregate as follows:

Assuming the ellipse and tangent straight line curve for proportionate weights of cement and aggregate of various sizes to determine the ideal distribution of sizes in a perfect mixture, proceed to form the mixture by mixing the different sizes of particles in conformity with this curve. The amount of any one size, for instance, 4-8, is determined in per cent. by the difference in length between the two ordinates to the curve from the No. 4 and No. 8 abscissæ respectively. All measurements are by weight.

If the aggregate considered is a sand, *i.e.*, particles not

larger than 1/4 in., the proportion of cement to aggregate should be 1 to 3. If the aggregate contains coarse particles as, a "Bank Run" gravel or crushed stone plus sand, the proportion of cement to aggregate should be 1 to 6.

The 2-in. cube and the standard briquette are the common forms of test specimens for a sand and the 6 in. cube or 8 in. × 16 in. cylinder for coarser aggregates. Enough material should be mixed in a batch so that at least three specimens may be made to determine the strength. Care should be taken that conditions of making test specimens should be uniform. The consistency and not the amount of water used for mixing should be constant for the different sizes. Tests may be made at 7 or 28 days.

CONCLUSIONS.—Is this a good method of grading?

Article 8

Tests of Road Materials

Experiment G-1

RATTLER TEST OF PAVING BRICK

PURPOSE.—To determine the effects of impact and abrasion in a standard rattler test.

NOTE.—Differentiate these effects in comparing different samples of brick.

References.

Judson—Roads and Pavements; Tillotson—Paving and Paving Materials; Baker—Roads and Pavements; Bryne—Highway Construction.—Specifications of N. B. M. A.

MATERIAL.—Use minimum number of whole brick that make a 1000 cu. in.

Note any surface evidences of lamination. Select

brick which are free from chipped corners and other defects.

Apparatus.—Rattler, 300 lb. of cast-iron shot of which 225 lb. is 1 1/2 in. cube and 75 lb. of larger shot 2 1/2 in.×2 1/2 in.×4 in. (see Judson). (Note. See that rattler is free from dust and that counter is attached.) Log board, scale and calipers and balance, dry kiln.

Procedure.—Place the required number of bricks in the rattler. See that the shot makes up the required weight for each size; if they do not, place an additional small shot in the rattler. Record the reading of the counter. Close the rattler and start. Note the rate which should be as near 30 r.p.m. as possible. When rattler has revolved 600 times by counter, stop the rattler, remove the brick dust, and weigh the charge. Place in rattler again and continue the test until rattler has revolved an additional 600 times and then clean and weigh. Repeat above process at end of another 600 revolutions.

Results.—Plot the per cent. of loss as ordinate, the abscissæ being the number of revolutions.

Look up standards for good brick in rattler test.

Report should be in general form.

Experiment G-2

Absorption Test.

Procedure.—Place 5 rattled brick in dry kiln 48 hours and weigh each brick separately to nearest gram. Then place in water completely submerged for 48 hours. Place strips 1/2×3/4 beneath the bricks and between them so that faces shall not be in contact. When removed from water, allow the water to drip from the surfaces for about 2 minutes, then weigh separately to nearest gram. (Note: When rattled brick are not available, use half-brick.)

Absorption.—Subtract the weight of the dry bricks from the weight of the wet bricks. Find the per cent. of gain in weight, which is called the per cent. of absorption.

See general form of report.

Experiment G-3

Abrasion Test of Road Materials

This test is intended to determine the wearing value of road materials.

References.

Year Books of American Society for Testing Materials.

Bulletin, No. 44, U. S., Dept. of Agriculture. Office of Public Roads.

Materials.—Any rock or like material used in road construction. At least 30 lb. of the material should be available for a test.

Procedure.—The material to be tested should be broken in pieces as nearly uniform as possible. There should be 50 pieces in the charge, the total weight of which shall be 5 kg. All test pieces shall be washed and thoroughly dried before testing. The charge is then placed in the Deval Abrasion machine and given 10,000 revolutions at the rate of 30 to 33 r.p.m.

The Deval Abrasion machine consists of one or more hollow iron cylinders, closed at one end and furnished with a tightly fitting cover at the other. The cylinders are 20 cm. in diameter and 34 cm. in depth inside dimensions. They are mounted on a shaft at an angle of 30° with the axis of rotation of the shaft.

At the end of 10,000 revolutions, the charge is removed and those particles retained on a 1/16-in. mesh sieve, are thoroughly washed and dried again.

Computations.—Compute the loss in per cent.

Compute the French Coefficient of wear.

Experiment G-4

Cementation Test of Rock or Gravel or Materials of Like Nature

This test is intended to determine the comparative value of dust from different rocks or gravels as a binder in the surface of roads.

Materials.—The materials consist of 1500 grm. of coarsely crushed rock broken to pass a 1/2-in. sieve or 1500 grm. of gravel as it comes from bank.

Special Apparatus.—A Ball Mill for grinding the materials. Cementation impact machine for testing briquettes.

Procedure.—Place 500 grm. of the rock together with 90 c.c. of water in the ball mill. The mill is then revolved at the rate of 2000 revolutions per hour for two and one-half hours, the action of the chilled iron balls in the mill grinds the sample to a stiff dough.

Place about 25 grm. of the dough in the cylindrical metal die for molding. The die is 25 mm. in diameter. By applying a load directly to the plunger of the die, run the plunger down to a maximum pressure of 132 kg. per square centimeter. This load is applied only for an instant and then released. Remove the briquette and measure the height, if it is not 25 mm. in height, the requisite amount of material should be added or subtracted to make the next briquette the required height.

At least 5 briquettes should be made from each sample. These are allowed to dry in air for 20 hours and in air of approximately 100° C., for 4 hours. After cooling 20 minutes in a desiccator they should be tested in the impact machine.

The briquette is placed directly on the anvil under the plunger. By placing a drop of shellac on the anvil

under the briquette, it can be made to stay in its position After adjusting the recording paper and needle, the motor is started. The mechanism is such that the briquette receives the blow of a 1 kg. hammer at the rate of 60 per minute. The number of blows it takes to break the specimen is recorded on the drum.

The number of blows necessary to destroy the resilience of the briquette, so that no action is recorded on the drum, is taken as the cementing value of the specimen. There should be obtained an average of at least five specimens to fix the cementing value of the material.

Experiment G-5

Hardness Test of Rock Road Materials.—Dorry Test

This test indicates the comparative hardness of rocks as indicated by their ability to withstand an abrasive force.

Special Apparatus.—A diamond core drill for cutting out test pieces. A Dorry Abrasion Machine for testing hardness.

Materials to be Tested.—Any rock in pieces large enough so that cylinders 25 mm. in diameter and 25 mm. in height may be cut from them.

Procedure.—Cut out specimens from rock by means of a diamond core drill. The ends may be squared by the diamond saw. At least two and preferably four specimens should be tested from each material.

These specimens should be dried to a constant weight at 100° C. Before placing in the machine they should be weighed. After placing two specimens in the machine start the motor and allow to run for 1000 revolutions at 28 r.p.m.

Reweigh the specimens and determine the loss.

The operation is repeated with the specimen reversed.

Calculations.—Express the loss as a per cent. of the original dry weight. Compute the coefficient of hardness.

Experiment G-6

Standard Toughness Test for Road Rock

In this connection, toughness of rock is taken to mean the power to resist fracture by impact.

Special Apparatus.—A core drill for cutting specimens.

An impact machine in which the anvil weighs 50 kg., the hammer weighs 2 kg., the intervening plunger weighs 1 kg. The plunger should bear upon the test piece with spherical surface of hardened steel having a radius of 1 cm.

Materials.—Any rock in pieces large enough to cut cylinders 25 mm. diameter and 25 mm. height. These should be cut perpendicular to the line of cleavage in the rock.

Procedure.—At least two and preferably four or more specimens should be tested for each rock. These should be dried in a constant weight before testing. The specimen should be adjusted in the machine, so that the center of its upper surface is tangent to the spherical surface of plunger. The test shall consist of 1 cm. fall of the hammer for the first blow and an increased fall of 1 cm. for each succeeding blow, till the piece is ruptured.

Calculations.—Compute the energy of the final blow. The toughness is represented by the number of blows necessary to break specimen.

APPENDIX I

Common Formulas

Tension.

Contraction of area at fracture equals

$$\frac{\text{Original area} - \text{area at fracture}}{\text{original area}}$$

Elongation in gage length equals:

$$\frac{\text{Length after fracture} - \text{gage length}}{\text{gage length}}$$

Tenison and Compression.

Church's Mechanics.

$$p = \frac{P}{F}$$

$$E_t = E_c = \frac{Pl}{F\lambda} = \frac{p}{\varepsilon}$$

$$U = \frac{1}{2} T'' \varepsilon V = \frac{1}{2} \frac{T''^2}{E} V$$

$$\text{Mod. of Res.} = \frac{1}{2} \frac{T''^2}{E}$$

Merriman's Strength of Materials.

$$S = \frac{P}{a}$$

$$E = \frac{Pl}{ae} = \frac{S}{\varepsilon}$$

$$K = \frac{1}{2} S \varepsilon V = \frac{1}{2} \frac{S^2}{E} V$$

$$\text{Mod. of Res.} = \frac{1}{2} \frac{S^2}{E}$$

Torsion (Round solid shafts)

$$p_s = \frac{Pae}{I_p}$$

$$E_s = \frac{Pal}{\propto I_p}$$

$$U = \frac{1}{2} Pa \propto$$

$$S = \frac{Ppc}{J}$$

$$F = \frac{Ppl}{J\phi}$$

$$K = \frac{1}{2} \frac{S^2}{F} \frac{r^2}{c^2} al$$

$$\text{Mod. of Res.} = \frac{1}{2} \frac{S^2}{F}$$

Bending.

$$p=\frac{Me}{I}=\frac{3}{2}\frac{Pl}{bh^2} \qquad S=\frac{Mc}{I}=\frac{3}{2}\frac{Pl}{bd^2}$$

$$E=\frac{1}{48}\frac{Pl^3}{dI} \quad \text{(Center Loading)} \quad E=\frac{1}{48}\frac{Pl^3}{fI}$$

$$E=\frac{23}{1296}\frac{Pl^3}{dI} \quad \text{(Third Point Loading)} \quad E=\frac{23}{1296}\frac{Pl^3}{dI}$$

$$U=\frac{1}{2}Pd \qquad K=\frac{1}{2}Pf$$

$$\text{Mod. of Res.}=\frac{1}{2}\frac{S^2}{E}$$

Impact Bending (Rectangular Beams).

$$p=3\frac{GHl}{bh^2\triangle}$$

$$E=\frac{GHl^3}{2\triangle^2bh^3}$$

Road Materials Formulæ

Deval Abrasion Test

$$\text{Loss per cent.}=\frac{\text{Original weight—final weight}}{\text{Original weight}}$$

French coefficient of wear =

$$\frac{20\times 20}{\text{Loss per kilogram of charge}}$$

Dorry Hardness Test

Coefficient of hardness $=20-1/3$ loss in weight after 1000 revolutions at 28 r.p.m.

LEGEND FOR ABOVE FORMULA

	Church	Merriman
Width	b	b
Height	h	d
Gage length or span	l	l
Area of cross section	F	a
Moment of inertia	I	I
Polar moment of inertia	I_p	J
Radius of gyration		r
Distance from neutral axis to extreme fiber	e	c
Total load (concentrated)	P	P
Unit stress	p	S
Unit stress at elastic limit tension	T''	
Total elongation in gage length at or before elastic limit	λ	e
Unit elongation	ε	ε
Twist in gage length (radians)	α	ϕ
External moment in torsion	Pa	Pp
Deflection	d	f
Mod. of elasticity (ten. and compression)	E	E
Mod. of elasticity (shear)	E_s	F
Resilience	U	K
IMPACT BENDING:		
Weight of hammer	G	
Span length	l	
Fiber stress	p	
Modulus of elasticity	E	
Total height of drop	H	
Deflection (total) deflection due to static load G + deflection due to blow	$\triangle$	

APPENDIX II

Strength Specifications for Steel and Iron
American Society for Testing Materials, Year Book 1912

Metal	Tensile strength lb. per square inch		Minimum elongation per cent.		Contraction of area per cent.
	Ultimate	Elastic limit	in 8 in.	in 2 in.	
BRIDGES:					
Structural steel..........	(desired) 60,000	....	$\frac{1,500,000}{\text{ultimate}}$	22	......
Rivet steel.............	(desired) 50,000	....	$\frac{1,500,000}{\text{ultimate}}$	....	......
Steel castings...........	65,000	....	....	18	......
BUILDINGS:					
Structural steel..........	55-65,000	½ ultimate	$\frac{1,400,000}{\text{ultimate}}$	....	......
Rivet steel.............	48-58,000	½ ultimate	$\frac{1,400,000}{\text{ultimate}}$	....	......
SHIPS:					
Structural steel	55-65,000	½ ultimate	$\frac{1,500,000}{\text{ultimate}}$	....	......
Rivet steel.............	48-58,000	½ ultimate	$\frac{1,500,000}{\text{ultimate}}$	....	......
Steel castings............	60,000	½ ultimate	....	18	......
BOILER AND RIVET STEEL:					
Flange steel............	55-65,000	½ ultimate	$\frac{1,500,000}{\text{ultimate}}$	....	......
Fire box steel...........	52-62,000	½ ultimate	$\frac{1,500,000}{\text{ultimate}}$	....	......
Boiler Rivet Steel........	45-55,000	½ ultimate	$\frac{1,500,000}{\text{ultimate}}$	....	......
STEEL SPLICE BARS...	55-65,000	½ ultimate	25	....	......
AXLES, DRIVING AND ENGINE TRUCK:					
Carbon steel...........	80,000	40,000	....	20	25
Nickel steel............	80,000	50,000	....	25	45
TIRES—DRIVING:					
Passenger engines........	105,000	....	....	12	16
Freight engines..........	115,000	....	....	10	14
Switching engines........	125,000	....	....	8	12
STEEL FORGINGS:					
Low carbon steel......... (under 10 in. diam.)	58,000	29,000	....	28	35
Carbon steel (annealed)... (under 10 in. diam.)	75,000	37,500	....	18	30

APPENDIX II (*Continued*)

Metal	Tensile strength lb. per square inch		Minimum elongation per cent.		Contraction of area per cent.
	Ultimate	Elastic limit	in 8 in.	in 2 in.	
Carbon steel (annealed) .. (under 10 in. diam.)	80,000	40,000	....	22	35
Between 10 in. and 20 in.	75,000	37,500	....	23	35
Over 20 in............	70,000	35,000	....	24	30
Carbon steel (oil tempered) (under 3 in. diam.)	90,000	55,000	....	20	45
Not exceeding 6 in. in thickness or diam.	85,000	50,000	....	22	45
Not exceeding 10 in. in thickness or diam.	80,000	45,000	....	23	40
Nickel steel (annealed) under 10 in. diam.	80,000	50,000	....	25	45
Between 10 in. and 15 in	80,000	45,000	....	25	45
Over 20 in. diam........	80,000	45,000	....	24	40
Nickel steel (oil temp.)					
Not exceeding 3 in. diam.	95,000	65,000	....	21	50
Not exceeding 6 in. diam.	90,000	60,000	....	22	50
Not exceeding 10 in. diam	85,000	55,000	....	24	45
STEEL CASTINGS:					
Hard castings...........	80,000	36,000	....	15	20
Medium castings.........	70,000	31,500	....	18	25
Soft castings............	60,000	27,000	....	22	30
WROUGHT IRON:					
Staybolt iron...........	49–53,000	0.6 ultimate	30	....	48
Engine Bolt Iron........	50–54000	0.6 ultimate	25	....	40
Refined Wrought Iron...	48,000	25,000	22	....	.....
GRAY CAST IRON:					
Light castings...........	18,000	....	....	....	.....
Medium castings.........	21,000	....	....	....	.....
Heavy castings..........	24,000	....	....	....	.....
Malleable cast iron......	40,000	....	....	2½	.....

NOTE.—When not otherwise stated values are the minimum allowed.

AMERICAN SOCIETY FOR TESTING MATERIALS

PHILADELPHIA, PA., U. S. A.

AFFILIATED WITH THE

INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS

STANDARD SPECIFICATIONS FOR CEMENT *

ADOPTED AUGUST 16, 1909

GENERAL OBSERVATIONS

1. These remarks have been prepared with a view of pointing out the pertinent features of the various requirements and the precautions to be observed in the interpretation of the results of the tests.

2. The Committee would suggest that the acceptance or rejection under these specifications be based on tests made by an experienced person having the proper means for making the tests.

SPECIFIC GRAVITY

3. Specific gravity is useful in detecting adulteration. The results of tests of specific gravity are not necessarily conclusive as an indication of the quality of a cement, but when in combination with the results of other tests may afford valuable indications.

FINENESS

4. The sieves should be kept thoroughly dry.

TIME OF SETTING

5. Great care should be exercised to maintain the test pieces under as uniform conditions as possible. A sudden change or wide range of temperature in the room in which the tests are made, a very dry or humid atmo-

* Authorized reprint from Proc. 1912, Amer. Soc. for Testing Materials.

sphere, and other irregularities vitally affect the rate of setting.

Constancy of Volume

6. The tests for constancy of volume are divided into two classes, the first normal, the second accelerated. The latter should be regarded as a precautionary test only, and not infallible. So many conditions enter into the making and interpreting of it that it should be used with extreme care.

7. In making the pats the greatest care should be exercised to avoid initial strains due to molding or to too rapid drying-out during the first twenty-four hours. The pats should be preserved under the most uniform conditions possible, and rapid changes of temperature should be avoided.

8. The failure to meet the requirements of the accelerated tests need not be sufficient cause for rejection. The cement may, however, be held for twenty-eight days, and a retest made at the end of that period, using a new sample. Failure to meet the requirements at this time should be considered sufficient cause for rejection, although in the present state of our knowledge it cannot be said that such failure necessarily indicates unsoundness, nor can the cement be considered entirely satisfactory simply because it passes the tests.

SPECIFICATIONS

General Conditions

1. All cement shall be inspected.

2. Cement may be inspected either at the place of manufacture or on the work.

3. In order to allow ample time for inspecting test-

ing, the cement should be stored in a suitable weather-tight building having the floor properly blocked or raised from the ground.

4. The cement shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment.

5. Every facility shall be provided by the Contractor and a period of at least twelve days allowed for the inspection and necessary tests.

6. Cement shall be delivered in suitable packages with the brand and name of manufacturer plainly marked thereon.

7. A bag of cement shall contain 94 lb. of cement net. Each barrel of Portland cement shall contain 4 bags, and each barrel of natural cement shall contain 3 bags of the above net weight.

8. Cement failing to meet the seven-day requirements may be held awaiting the results of the twenty-eight-day tests before rejection.

9. All tests shall be made in accordance with the methods proposed by the Committee on Uniform Tests of Cement of the American Society of Civil Engineers, presented to the Society January 21, 1903, and amended January 20, 1904, and January 15, 1908, with all subsequent amendments thereto. (See addendum to these specifications.)

10. The acceptance or rejection shall be based on the following requirements:

Natural Cement

11. Definition.—This term shall be applied to the finely pulverized product resulting from the calcination of an argillaceous limestone at a temperature only sufficient to drive off the carbonic acid gas.

FINENESS

12. It shall leave by weight a residue of not more than 10 per cent. on the No. 100, and 30 per cent. on the No. 200 sieve.

TIME OF SETTING

13. It shall not develop initial set in less than ten minutes; and shall not develop hard set in less than thirty minutes, or in more than three hours.

TENSILE STRENGTH

14. The minimum requirements for tensile strength for briquettes one square inch in cross section shall be as follows, and the cement shall show no retrogression in strength within the periods specified:

Age	*Strength*
Neat Cement	
24 hours in moist air	75 lb.
7 days (1 day in moist air, 6 days in water)	150 lb.
28 days (1 day in moist air, 27 days in water)	250 lb.
One Part Cement, Three Parts Standard Ottawa Sand	
7 days (1 day in moist air, 6 days in water)	50 lb.
28 days (1 day in moist air, 27 days in water)	125 lb.

CONSTANCY OF VOLUME

15. Pats of neat cement about 3 in. in diameter, 1/2 in. thick at center, tapering to a thin edge, shall be kept in moist air for a period of twenty-four hours.

(a) A pat is then kept in air at normal temperature.

(b) Another is kept in water maintained as near 70° F. as practicable.

16. These pats are observed at intervals for at least 28 days, and, to satisfactorily pass the tests, shall remain firm and hard and show no signs of distortion, checking, cracking, or disintegrating.

Portland Cement

17. Definition.—This term is applied to the finely pulverized product resulting from the calcination to incipient fusion of an intimate mixture of properly proportioned argillaceous and calcareous materials, and to which no addition greater than 3 per cent. has been made subsequent to calcination.

SPECIFIC GRAVITY

18. The specific gravity of cement shall not be less than 3.10. Should the test of cement as received fall below this requirement, a second test may be made upon a sample ignited at a low red heat. The loss in weight of the ignited cement shall not exceed 4 per cent.

FINENESS

19. It shall leave by weight a residue of not more than 8 per cent. on the No. 100, and not more than 25 per cent. on the No. 200 sieve.

TIME OF SETTING

20. It shall not develop initial set in less than thirty minutes; and must develop hard set in not less than one hour, nor more than ten hours.

TENSILE STRENGTH

21. The minimum requirements for tensile strength for briquettes 1 sq. in. in cross section shall be as follows, and the cement shall show no retrogression in strength within the periods specified:

Age	*Neat Cement*	*Strength*
24 hours in moist air		175 lb.
7 days (1 day in moist air, 6 days in water)		500 lb.
28 days (1 day in moist air, 27 days in water)		600 lb.

One Part Cement, Three Parts Standard Ottawa Sand

7 days (1 day in moist air, 6 days in water)	200 lb.
28 days (1 day in moist air, 27 days in water	275 lb.

CONSTANCY OF VOLUME

22. Pats of neat cement about 3 in. in diameter, 1/2 in. thick at the center, and tapering to a thin edge, shall be kept in moist air for a period of twenty-four hours.

(a) A pat is then kept in air at normal temperature and observed at intervals for at least 28 days.

(b) Another pat is kept in water maintained as near 70° F. as practicable, and observed at intervals for at least 28 days.

(c) A third pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel for five hours.

23. These pats, to satisfactorily pass the requirements, shall remain firm and hard, and show no signs of distortion, checking, cracking, or disintegrating.

SULPHURIC ACID AND MAGNESIA

24. The cement shall not contain more than 1.75 per cent. of anhydrous sulphuric acid (SO_3), nor more than 4 per cent. of magnesia (MgO).

APPENDIX III

Forms of Test Pieces

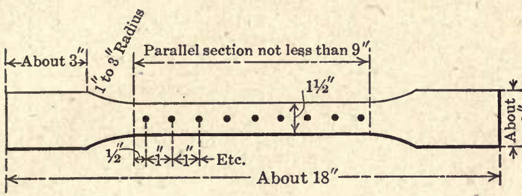


FIG. 1.

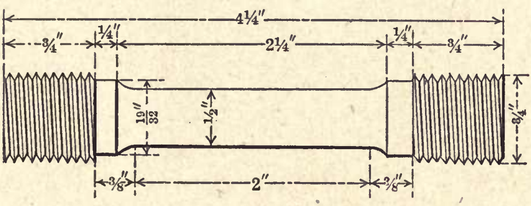


FIG. 2.

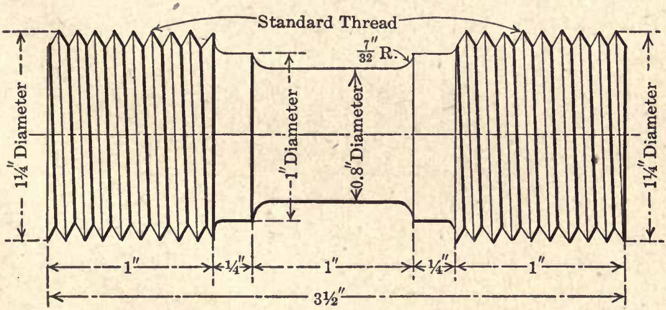


FIG. 3.—Arbitration test bar. Tensile test piece.

FIG. 1.—Wrought iron, structural steel and boiler plate. Plate metal in general.
FIG. 2.—Structural steel, wrought iron, steel castings and forgings, axle and tire steel.
FIG. 3.—Cast iron.

APPENDIX IV

Strength Tables

TABLE I.—MECHANICAL PROPERTIES OF IRON AND STEEL. VALUES ARE RANGE OF AVERAGE, EXCLUDING HIGH AND LOW INDIVIDUAL RESULTS

Material	Spec. grav.	Tension—(1000 lb. per sq. in.) Ult. strength	Elastic ratio at		Ultimate elongation	Mod. of elasticity	Compress at failure	Shear Ultimate strength	Bending Mod. of rupture
		Sm	Sp	Sy	Eu	E	Sc	Ss	Sr
Cast iron (gray iron)......	7.207	15–18	0.33	......	0.1–1.0 (in 2″)	12–14,000	Sc = 6Sm	Ss = 1.1Sm	Sr = 2Sm
Malleable cast iron........	......	25–32	......	0.60	1.0–3.0(in 4″)	....	Sc = 4Sm	....	Sr = 2Sm
Wrought iron............	7.78	42–52		0.66	22–30 (in 8″)	26–29,000	Sc = Sy	Ss = .85 Sm	Sr = Sm
Steel:									
Extra soft..............	......	45–55	Ratio of Sp to Sm = 0.5	0.66	27–33 (in 8″)	Modulus of elasticity of all steels varies from 28–31,000,000. Average = 30,000,000 lb. sq. in.	Sc = Sy (When short cylinder is tested on artificial ultimate strength > Sy may appear	Ss = 0.75 Sm for hard + soft steels (Arnold)	Sr = Sy
Soft (C. 0.08–0.15)......	7.833	50–60		......	25–30 (in 8″)				
Medium (0.15–0.30).....	......	60–70		0.63	22–25 (in 8″)				
Hard (C. 0.3 up)	......	70–80		0.55	22–18 (in 8″)				
Rails (0.64–0.55)	......	101–102		0.50	12–15 (in 2″)				
Steel castings............	7.917								
Soft....................	......	60–72		0.66	22–up (in 2″)				
Medium..................	......	72–78		......	16–22 (in 2″)				Sr = Sy
Hard....................	......	78–up		......	12–16 (in 2″)				
Steel forgings............	......	75–90		......	22–24 (in 2″)				
Spring steel:									
Untempered..............	......	101–135			2.8–6.5(in 8″)				
Tempered................	......	130–200	0.85	......	2.1–0.5 (in 8″)				
Nickel steel:									
Structural..............	......	100–120	0.50	0.58	16–20 (in 8″)				
Forging (annealed).......	......	80	......	......	30 (in 2″)				
Forging (oil-tempered)...	......	98	......	......	25 (in 2″)				
Vanadium steel:									
(a) Annealed............	......	54–96	......	......	22–44 (in 2″)				
(b) Oil-tempered.........	......	125–232	......	......	11–21 (in 2″)				

TABLE I*a*.—MECHANICAL PROPERTIES OF COPPER AND ALLOYS STRENGTH—in 1000 lb. per sq. in. units.

Metals	Spec. grav.	Tens. strenght		Mod. of elasticity	Comp. strength	Bending mod. of rupture	Shear
		El. limit	Ultimate				
Copper, Cast	8.87	11–15	22–28	10–15	39–48	20–40	22–28
Copper, Wrought	8.90	....	29–36	12.5–16.8	58.000	30–60	
Brass, Cast	8.00	....	22.4–26.9	8.6–10	13.7 (?)	....	22.4–26.9
Aluminium, Cast	2.57	4–6.5	11–16.5	8–11	12	2.34	12–16
Aluminium, Rolled	2.72	12.5–14	16.5–22.4	9.7–10	18.8 el. lim		
Zinc, Cast	7.1	4–9	2.2–6.75	12–14	22	7.5	
Zinc, Wrought	7.2	....	15.7–22.4				
Tin	7.28	2.0	4–5	3–6	6.4	4.15	
Gun Metal	8.6	....	25–50	10	....	....	33.6
Phosphor Bronze	8.7	20.0	36–40.5	12–14	....	....	14.5
Manganese Bronze	......	30	65–85				
Tobin Bronze	......	51–56	66–80	4.5			
Aluminium Bronze (90% Cu, 10 % Al)	7.7	....	100	16.8	....	....	56

TABLE I*b*.—STRUCTURAL TIMBER
STRENGTH—expressed in 100 lb. per sq. in.

Kind of timber	Bending		Shearing		Compression	
	Extreme fib. stress	Modulus of elasticity	Parallel to grain	Longitudinal shr. in beams	Perpendic. to grain	Parallel to grain
	Average ultimate	Average	Average ultimate	Average ultimate	Elastic limit	Average ultimate
Douglas fir	61	15,100	6.9	2.7	6.3	36
Longleaf pine	65	16,100	7.2	3.0	5.2	38
Loblolly and Shortleaf pine	56	14,800	7.1	3.3	3.4	34
White Pine	44	11,300	4.0	1.8	2.9	30
Spruce	48	13,100	6.0	1.7	3.7	32
Norway pine	42	11,900	5.9	2.5	....	26
Tamarack	46	12,200	6.7	2.6	....	32
Western hemlock	58	14,800	6.3	2.7	4.4	35
Redwood	50	8,000	3.0	....	4.0	33
Bald cypress	48	11,500	5.0	....	3.4	39
Red cedar	42	8,600	....	....	4.7	28
White oak	57	11,500	8.4	2.7	9.2	35

TABLE I*c*.—STONE AND BRICK

ULTIMATE STRENGTH—in units of 1000 lb. per sq. in. (subject to variation of 50 per cent. of average each way)

Material	Spec. grav.	Comp. Sc	Tens. Sa	Flex. Sr	Shear Sr	Mod. of elast E (1)	Absorption
			In per cent. of Sc				
Granite	2.67	19.4	About 4 %	8.5	Varies with method of test from 10 to 20 %	4600	1/750
Limestone	2.53	9.5		18.0		4700	1/38
Limestone Oolitic	2.48	6.7		18.0		4700	1/23
Marble	2.72	12.7		15.0		7000	1/300
Sandstone	2.22	9.3		14.0		2200	1/24
Slate	2.77	14.0		15.0		....	1/435
Trap	2.92	32.0 (2)					
Brick (3)							
Common	......	4.0	} 15.0			1300?	1/3
Hard burned	......	12.0				4000	1/6
Paving (best) (4)	......	7.5	......	33.0	....	....	1/100
Sand lime	......	3.5	......	15.0	....	....	1/10
Brick masonry							
Lime mortar	......	Sc = 0.14 Sc of brick					
Cement mortar	......	Sc = 0.23 Sc of brick					

(1) at working stressess

(2) Bauschinger. Poison's ratio = 1/4

(3) Tests on 1/2 brick in plaster of Paris

(4) Rattler loss N. B. M. A. test = 18%

INDEX

A

B

C

G

V

W

Y